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Seattle Dept. of Water, WA

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August 1983

SEATTLE DISTRIBUTION SYSTEM CORROSION CONTROL STUDY

Volume IV. On-Site Evaluation of Corrosion Treatment

by

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16. ABSTRACT

For 8 months, the Seattle Water Department conducted a corrosion treatment pilot plant study, obtaining data on the treatment of Tolt River water with lime and sodium carbonate. Pipe loop tests were conducted to determine the appropriate chemical start-up procedures for two full-scale corrosion treatment facilities; to document the effectiveness of the corrosion treatment program in suppressing corrosion, metal leaching and tuberculation in older galvanized steel premise plumbing systems; to document the bacterial effects of the corrosion treatment program on water quality; and to anticipate any possible customer problems caused by implementation of the corrosion treatment program.

The study monitored the effects of simulated corrosion treatment start-up on chemical and microbial water quality from an old galvanized plumbing system. Standing water samples collected after treatment start-up displayed increased iron deposits, organic debris and bacterial populations compared to untreated standing water samples. Zinc leaching was reduced during treatment from pH 6 to pH 7 and increased from pH 7 to pH 8. Iron leaching was found to increase by approximately 38% during treatment start-up, while copper and lead leaching were reduced by 53% and 57%, respectively. Corrosion treatment also resulted in a reduction of approximately 32% in the tuberculation rate.

Based on this pilot study, a full-scale corrosion treatment schedule is recommended which minimizes possible water quality problems caused by the implementation of corrosion treatment. The recommended approach includes the gradual addition of lime and sodium carbonate to a final treatment pH of 8.3.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report presents the results and conclusions from on-site testing of corrosion treatment for an aggressive water supply. The data support the conclusion that substantial corrosion reduction can be achieved by treatment.

Francis T. Mayo
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ABSTRACT

A study was conducted in Seattle, Washington, to evaluate the use of lime and sodium carbonate in surface water supplies to control corrosion of plumbing materials. The intent of this investigation was fourfold: (1) To determine the appropriate chemical start-up procedures for two full-scale corrosion treatment facilities; (2) to document the effectiveness of the corrosion treatment program in suppressing corrosion, metal leaching, and tuberculation in older galvanized steel premise plumbing systems; (3) to document the bacterial effects of the corrosion treatment program on water quality; and (4) to anticipate any possible customer problems caused by implementation of the corrosion treatment program. This volume is the fourth in a series of seven publications presenting the results of the Seattle Distribution System Corrosion Control Study.

The study described in this volume monitored the effects of a simulated corrosion treatment start-up on the chemical and microbial quality of water from an old galvanized plumbing system. Periodic 24-hour standing, running, and control samples were analyzed for metal concentrations, physical parameters, and microbial quality before and after corrosion treatment. The microbial quality of the water and pipe incrustations were examined through the use of selective enrichment culture media and scanning electron microscopy. X-ray energy-dispersive microanalysis was employed to determine the chemical composition of the tubercles and suspended particulate matter in the water. Headloss in the test pipe loop system was used as an indication of pipe blockage.

The most frequently observed water quality changes occurring before and after treatment in the pipe loop in 24-hour standing water (as opposed to running water) were higher bacterial plate counts (by two to three orders of magnitude), increased levels of iron, turbidity, and apparent color.

Standing water samples collected after treatment start-up displayed increased iron deposits, organic debris, and bacterial populations when compared with untreated standing water samples. Iron-oxidizing and sulfate-reducing organisms were shown to exist within the pipe loop system in both the standing water and tubercular incrustations. Opportunistic pathogens and coliform antagonists (including Pseudomonas and Flavobacterium) were present in standing water samples and increased in number with treatment start-up. The opportunistic pathogens comprised approximately 77% of the total standard plate count isolates in 24-hour standing water samples, while the coliform antagonists accounted for approximately 71% of the total SPC isolates. The public health significance of sessile microbial communities in drinking water is also discussed.

In standing water, zinc leaching was decreased during treatment from pH 6 to 7 and increased from pH 7 to 8. Iron leaching increased by approximately 38% during treatment start-up, whereas copper and lead leaching were reduced by 53% and 57%, respectively.

In running water, reductions occurred in zinc and iron leaching during treatment start-up. No significant change occurred in lead or cadmium leaching.

Corrosion treatment resulted in a reduction of approximately 32% in the tuberculation rate and subsequent pipe blockage.

Based on these test results, a full-scale corrosion treatment schedule is recommended to minimize possible water quality problems caused by the implementation of corrosion treatment. The recommended approach includes the gradual addition of lime and sodium carbonate to a final treatment pH of 8.3.

This report was submitted in fulfillment of Grant No. R 806686 010 by the Seattle Water Department under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from January 1981 to August 1981, and work was completed as of January 1982.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A.A.S.	-- atomic absorption spectrophotometry
^{o}C	-- degrees Celsius
cm	-- centimeters
cm^2	-- centimeters squared
EDAX	-- energy dispersive X-ray analysis
EIS	-- environmental impact statement
EPA	-- U.S. Environmental Protection Agency
$[Halogen + SO_4^{=}]/Alk$	-- [halogen + sulfate] / alkalinity ratio
L	-- liters
L/s	-- liters per second
MCL	-- maximum contaminant level
mg/L	-- milligrams per liter
m^3/d	-- cubic meters per day
SEM	-- scanning electron microscopy
SWD	-- Seattle Water Department
yr	-- year
µg/L	-- micrograms per liter
µm	-- micrometers
µmhos	-- micromhos

SYMBOLS

C	-- carbon
$CaCO_3$	-- calcium carbonate
CaO	-- calcium oxide (lime)
Cd	-- cadmium
CO_2	-- carbon dioxide
Cu	-- copper
Fe	-- iron
H^+	-- hydrogen ion
HCO_3^-	-- bicarbonate
H_2O	-- water
Na_2CO_3	-- sodium carbonate
pH	-- -log $\langle H^+ \rangle$

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SECTION 1

INTRODUCTION

This study is Volume IV of a six-volume series presenting results of research conducted under the Seattle Distribution System Corrosion Control Study. Presented in this volume are the results of an on-site chemical treatment study for internal corrosion control in the Tolt distribution system. Volumes I and II present pilot test results and recommended specific chemical treatment for internal corrosion control in the Cedar and Tolt distribution systems, respectively. Volume III evaluates the potential of drinking water contamination from the corrosion of tin/antimony solder. Volume V presents a laboratory electrochemical technique for corrosion rate determinations in drinking water. Volume VI addresses the counteractive effects of disinfection (chlorination) and corrosion control (pH/alkalinity adjustment).

BACKGROUND INFORMATION

Seattle Service Area

The Seattle Water Department (SWD) service area includes Seattle proper and also most of the metropolitan area. It extends from Edmonds on the north to just south of Des Moines, and easterly from Puget Sound to Lake Sammamish at the foot of the Cascade range. Nearly 1 million persons (or about 83% of the population of King County) are served directly or indirectly by the SWD. Average total water consumption is 609,000 m^3/d, and summer peak day use has reached 1.3 million m^3/d. Approximately two-thirds of this water is sold directly to the SWD retail customers, and the remaining portion is delivered at wholesale rates to suburban water districts and municipalities, who in turn sell it to their direct service customers.

Water Sources

The primary sources of Seattle water are the Cedar and Tolt rivers on the western slope of the Cascade Mountains in eastern King County. These two rivers furnish high quality mountain water of unusual clarity. The Cedar River water supply system (in operation since 1901) serves the southern region of Seattle and parts of south King County. The Tolt, which was added to the City system in 1964, generally serves the area north of the Lake Washington Ship Canal and the water purveyors on the east side of Lake Washington. These two sources feed the distribution system from opposite ends, a feature that affords excellent hydraulic characteristics. Figure 1 illustrates the major facilities of the system.

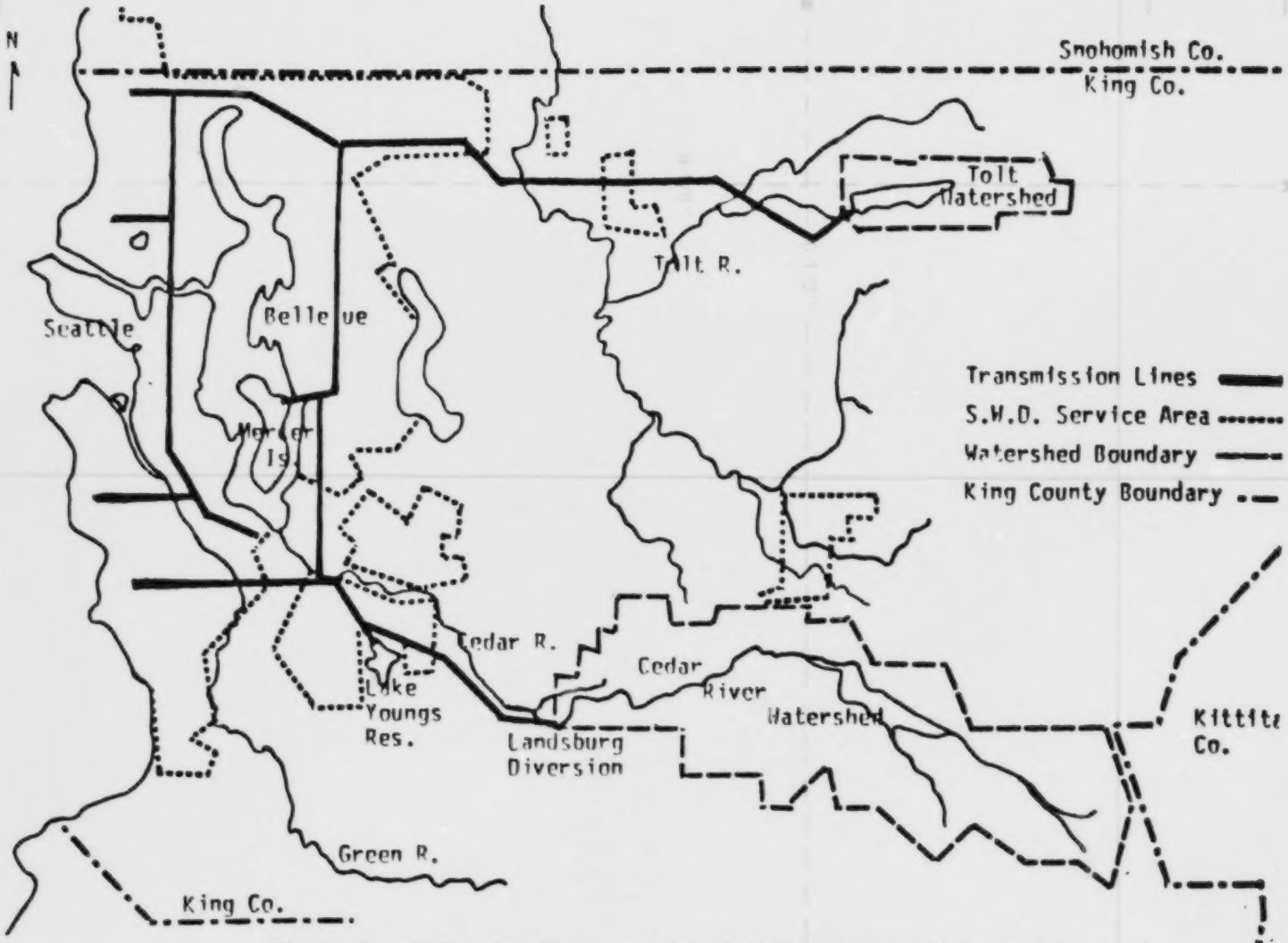

Figure 1. Major facilities of the Seattle distribution system.

Water Treatment

Currently, the treatment of both water supplies consists of intake screening, chlorination, and fluoridation. Before distribution, the water is rechlorinated as it leaves the open in-town reservoirs to assure the free chlorine residual necessary to maintain adequate levels of disinfection. Compared with most other major water utilities in this country, the present treatment is minimal. Many utilities are required to treat their water extensively with coagulation and filtration techniques to render it safe to drink. The SWD's emphasis on watershed protection, together with the large storage reservoir system to meet demands during periods of high turbidity, has enabled Seattle to meet National Interim Primary Drinking Water Regulations[1] without major modifications to the existing facilities.

Existing Facilities on the Tolt and Cedar River Systems

The Tolt River system originates in a 54 km^2 area watershed, which is narrow and steep and has been prone to slide activity. Ownership in the watershed is about equally divided between the Weyerhaeuser Company, the U.S. Forest Service, and the SWD. Ten major streams feed the South Fork Tolt Reservoir, a 69 million m^3, manmade storage reservoir with a maximum pool elevation of 536 m. The water enters an 84-cm-diameter, 7.7 km pipeline through one of three intakes located at different depths in the reservoir. Upon discharge from the pipeline, water enters the pressure-regulating basin, a 108,000-m^3 reservoir at an elevation of 231 m. The purpose of the pipeline and the regulating basin is to dissipate 305 m of head. Water then enters a 168-cm-diameter transmission line, where it is chlorinated, fluoridated, and subsequently discharged into the Seattle distribution system.

The Cedar River system originates in a 370-km^2 watershed located in eastern King County. Eighty percent of the ownership of the watershed is held by the City of Seattle. The remaining 20% is divided between the U.S. Forest Service and the Weyerhaeuser Company.

From the watershed, the river flows into Morse Lake, which is located on the site of the naturally occurring, inundated Cedar Lake. Water is normally released from Morse Lake back into the natural river channel through a power-generating station located at Cedar Falls. Water flows approximately 18 km before it is diverted at the Landsburg intake into a 2.44-m-diameter tunnel for transmission to the Seattle area.

At Landsburg, the water is treated by intake screening, chlorination, and fluoridation. After treatment, the water can be directed into the distribution system or into Lake Youngs, a large storage reservoir located just southeast of Seattle. Water is again rechlorinated at the outlet from Lake Youngs.

Tolt and Cedar Corrosion Treatment Facilities

In July 1980, bids to construct new chemical treatment facilities at the outlets from the Tolt Regulating Basin and Lake Youngs were accepted by the

SWD. The Tolt treatment facility includes a lime silo, lime feeding and pumping equipment, and sodium carbonate feeding and pumping equipment. Additional space has been provided at this site for the addition of silicate treatment if needed. The Cedar treatment facility includes a lime silo and lime feeding and pumping equipment. Additional space has been provided at this site for the addition of sodium bicarbonate treatment if needed. The facilities are expected to be completed by November 1981.

Internal Corrosion Problem

Water quality deterioration in home and building plumbing systems is a major concern of the SWD. Several projects that have examined the corrosivity of its water supplies have well documented that corrosion, although not a major concern in the distribution system, causes several problems in premise plumbing. In addition to causing the obvious aesthetic problems of rusty water, red and blue staining, and metallic tastes, plumbing corrosion is responsible for a sizable economic burden to Seattle homeowners and possibly some long-term health impacts to those with high environmental exposure to lead, as well as exposure to increased levels of opportunistic pathogens.

Aesthetics --

Customer complaints of rusty water, stained fixtures, and metallic tastes are frequently received from within the water distribution system. This problem has been well documented by accurate complaint records and by a questionnaire survey conducted by the SWD in 1973. The survey, which was distributed to 15,000 customers (10% of all services within the direct service area), showed that 16.7% of customers in the Cedar water distribution system and 8.3% of customers in the Tolt water distribution system experienced corrosion-related problems.[2]

Economics --

Significant corrosion of piping occurs in the premise plumbing systems served by Cedar and Tolt water. The average estimated life span of hot water galvanized and copper pipes is approximately 35 years in the Cedar system and 25 years in the Tolt system. The forecasted 1978 average annual cost for maintaining serviceability in these pipes was estimated to be approximately $7.8 million.[2]

Health Impact --

Evidence gathered after 1972 demonstrates that the levels of lead (Pb), copper (Cu), and Iron (Fe) often exceed maximum contaminant levels[3] (MCL's) in overnight standing Cedar tap water (Table 1).

Cadmium (Cd) and zinc (Zn) also increase after overnight standing in home plumbing, but they rarely exceed their MCL's.

Although the health impact of metal levels in overnight standing water is not an acute problem, it would be desirable to reduce exposure to metals, especially lead and cadmium.

TABLE 1. PERCENTAGE OF SAMPLES EXCEEDING EPA MAXIMUM CONTAMINANT LEVELS.

Survey	Water Supply	Primary Contaminants: Lead 0.05 mg/L R*	Lead 0.05 mg/L S†	Cadmium 0.01 mg/L R	Cadmium 0.01 mg/L S	Secondary Contaminants: Copper 1 mg/L R	Copper 1 mg/L S	Iron 0.3 mg/L R	Iron 0.3 mg/L S	Zinc 5 mg/L R	Zinc 5 mg/L S	Color 15 units R	Color 15 units S	Manganese 0.05 mg/L R	Manganese 0.05 mg/L S
EPA§ (1972)	Tolt	0	23	0	9	3	23	15	73	0	9	-	-	0	5
SWMS‡ (1974-75)	Tolt	0	10	0	0	1	9	19	76	0	1	24	87	0	10
	Cedar	0	16	0	2	0	10	8	60	0	3	0	56	0	0
RWQM# (1979-80)	Tolt	0	9	0	0	2	23	20	79	0	0	-	-	-	-
	Cedar	0	6	0	0	0	4	11	76	0	0	-	-	-	-

*R = Running cold water samples.
†S = Overnight standing cold water samples.
‡ = Seattle Water Metals Survey.[4]
§ = Study of Corrosion Products in the Seattle Water Department Tolt Distribution System.[5]
# = Seattle's Residential Water Quality Monitoring.

Causes of Corrosion

Although the quality of both the Cedar and Tolt water supplies is quite high, both are corrosive to premise plumbing systems. The corrosiveness of the water results from several related factors, which include:

Acidity as indicated by low pH; after chlorination and fluoridation, pH is 6.8 to 7.2 for the Cedar supply and 5.8 to 6.2 for the Tolt supply;

A dissolved oxygen concentration that is at saturated conditions;

Insufficient calcium and bicarbonate alkalinity in the water to form protective calcium carbonate films on pipe surfaces;

A relatively high [halogen + sulfate] / alkalinity ratio [(Halogen + $SO_4^=$)/ Alk] of 0.5 to 0.8 for the Cedar and 2.5 for the Tolt, which is an indicator of conditions favorable to pitting corrosion.

In 1970, three factors combined to intensify the corrosiveness of both water supplies: (1) To decrease the occurrence of positive bacteriological samples within the distribution system, the chlorine dosage at the open reservoir outlets was increased. (2) At the request of the U.S. Public Health Service, ammoniation of the water supply was stopped to enable a free chlorine residual to be maintained throughout the distribution system. This change from combined chlorination to free chlorination was implemented to provide quicker, more effective disinfection of the unfiltered water supply. (3) Based

on a vote of the Seattle citizens in 1968, fluoridation with hydrofluosilicic acid began in 1970.

Internal Corrosion Study

In December 1975, the City of Seattle retained a consulting engineering firm to perform a detailed analysis of the corrosion problem and to recommend possible solutions. The Internal Corrosion Study,[6] which included a nine-month pilot plant investigation, confirmed the corrosiveness of Seattle water, the causes of corrosion, and the impacts associated with the corrosive water. The study also evaluated alternative measures to reduce the corrosiveness of the water supply. Corrosion reduction alternatives investigated included alternative methods of disinfection and fluoridation, blending with groundwater supplies, and the addition of corrosion inhibitor chemicals.

Based on the findings of the consultant study and the conclusions of pilot plant investigations, an Internal Corrosion Control Management Plan was developed. Because the very low level of mineral solids, pH, and alkalinity constitute the major causes of the waters' corrosiveness, the proposed plan was designed to correct the natural deficiency of minerals in Seattle's water. The natural deficiency of calcium, silicate, carbonate/bicarbonate alkalinity ions was proposed to be corrected by the addition of lime and sodium bicarbonate to both supplies and possibly sodium silicate to the Tolt supply.

Tolt and Cedar Pilot Plant Studies

The Tolt[7] and Cedar[8] pilot plant studies were conducted in 1979-80 to precisely define chemical treatment and dosages needed for corrosion control in both water supplies, and to document further the effects of such treatment. For the Cedar supply, two water treatments were tested - the addition of lime only and the addition of lime plus sodium bicarbonate. For the Tolt supply, three water treatments were tested - the addition of lime plus sodium carbonate, lime plus sodium bicarbonate, and lime plus sodium bicarbonate plus silicate.

These studies recommended the addition of lime only to the Cedar supply and lime plus sodium carbonate to the Tolt supply for internal corrosion control. The treatments were designed to achieve the water quality characteristics listed in Table 2. The recommendations were based upon the overall corrosion protection each treatment affords to commonly used plumbing materials, the treatment cost, and availability of chemicals. The treatment was designed primarily for the protection of copper plumbing systems from corrosion and is expected to reduce copper corrosion rates by 60% to 80%. The pilot plant studies, however, were inconclusive as to the effects of treatment on galvanized plumbing.

STUDY OBJECTIVES

The objectives of this research were to:

(1) Determine appropriate chemical start-up procedures for the Tolt

TABLE 2. PRESENT AND PROPOSED WATER QUALITY CHARACTERISTICS

Parameter	Present Quality of Chlorinated and Fluoridated Water		Proposed Water Quality After Corrosion Treatment	
	Cedar	Tolt	Cedar	Tolt
pH (pH units)	6.8-7.4	5.8-6.2	7.8-8.3	7.8-8.3
Alkalinity (as $CaCO_3$)	15-18 mg/L	2 mg/L	20 mg/L	14 mg/L
(Halogen + Sulfate)/ Alkalinity Ratio	0.5-0.8	2.5-4.5	0.5	0.5

and Cedar full-scale corrosion treatment facilities;

(2) Document the effectiveness of the corrosion treatment program in suppressing corrosion, metal leaching, and tuberculation in older galvanized steel premise plumbing systems;

(3) Document the bacterial effects of the corrosion treatment program on water quality; and

(4) Anticipate any possible customer problems caused by the implementation of the corrosion treatment program.

SCOPE OF STUDY

During the period January 1981 to August 1981, tests designed to simulate corrosion treatment start-up were conducted at the City of Seattle Fire Station No. 35. This test site was chosen because it contained older galvanized plumbing that experiences severe corrosion-related water quality problems. Also, the test site was located in the Tolt distribution system, where the changes in water quality caused by corrosion treatment will be greater than those in the Cedar distribution system.

The corrosion tests documented the effects of corrosion treatment start-up based on metal leaching, bacteriological water quality, aesthetic water quality, and pipe tuberculation. Running water samples and 24-hour standing samples were collected from a 8.5-m pipe loop system. The samples were collected before treatment to establish baseline data and during the simulated treatment start-up.

SECTION 2

CONCLUSIONS

CHEMICAL TREATMENT START-UP AT THE TOLT AND CEDAR CORROSION TREATMENT PLANTS

Based on the results of this research effort and on treatment plant operational constraints, a chemical start-up procedure for full-scale corrosion treatment was developed (Table 3). The procedure was designed to minimize the detrimental effects of a change in water quality in premise galvanized plumbing systems.

THE EFFECTS OF TREATMENT START-UP ON WATER QUALITY AT THE CUSTOMER'S TAP

The changes that will occur in overnight standing and running water quality at the customer's tap during treatment start-up will vary depending on the parameter under consideration. In running water, reductions were found to occur in zinc leaching and iron leaching during treatment start-up. No appreciable change occurred in lead leaching, cadmium leaching, apparent color, and turbidity concentrations in running water.

TABLE 3. CHEMICAL START-UP PROCEDURE FOR TOLT AND CEDAR CORROSION TREATMENT PLANTS

	Tolt Supply			Cedar Supply	
Days	Lime Dosage mg/L CaO	Sodium Carbonate Dosage, mg/L Na_2CO_3	pH	Lime Dosage mg/L CaO	pH
1-7	0.8	0	6.3	0	7.2
8-14	1.7	0	6.6	0	7.2
15-28	1.7	4.0	7.1	0	7.2
29-41	1.7	6.0	7.5	1.0	7.5
42	1.7	9.0	8.3	1.7	8.3

In standing water, zinc leaching was reduced during treatment from pH 6 to 7, and it increased from pH 7 to 8. Iron leaching was found to increase by approximately 38% during treatment start-up, whereas copper and lead leaching were reduced by 53% and 57%, respectively. Also, apparent color and turbidity increased in standing water during treatment start-up.

Assessment of the bacterial effects of corrosion treatment on water quality showed the 24-hour standing water standard plate counts exhibited an increase of two to three orders of magnitude of microorganisms per mL of sample compared with those counts received from the running water samples. Standing water samples collected after initiation of treatment displayed increased iron deposits, organic debris, and bacterial populations compared with untreated standing water samples (see Figures D-16 to D-19, Appendix D). Iron-oxidizing and sulfate-reducing organisms were shown to exist within the pipe loop system in both the standing water and tubercular incrustations. Stalk- and bud-producing organisms (e.g., Caulobacter spp.) were observed in the water samples as well as attached to the surface of (or embedded in) the tubercles. Opportunistic pathogens and coliform antagonists, includi Pseudomonas and Flavobacterium, were detected in standing water samples, increasing in number with treatment start-up.

EFFECTIVENESS OF CORROSION TREATMENT ON OLD GALVANIZED PLUMBING SYSTEMS

Corrosion in old galvanized plumbing systems will only be slightly reduced with corrosion treatment. Corrosion treatment will result in a reduction of approximately 32% in the tuberculation rate and subsequent pipe blockage. Iron leaching from the old galvanized pipe, however, will not be substantially reduced by corrosion treatment and may increase, depending on the condition of the pipe.

SECTION 3

RECOMMENDATIONS

GENERAL

This section of the report makes recommendations regarding additional research needs and further evaluations in the area of corrosion control.

SEATTLE WATER DEPARTMENT

The SWD should:

- Implement the corrosion treatment start-up procedures detailed in this report for the Tolt and Cedar water supplies.
- Determine to what extent chemical treatment for corrosion control decreases the disinfection power of free chlorine.
- Monitor bacteriological water quality in the distribution system before and after the implementation of full-scale treatment.
- Evaluate the possibility of trihalomethane formation in Tolt and Cedar water with respect to chemical treatment.
- Determine whether corrosion treatment will cause post-precipitation problems in the distribution system.

U.S. ENVIRONMENTAL PROTECTION AGENCY

The EPA should:

- Develop a standard method for the determination of metal leaching from plumbing materials.
- Publish a state-of-the-art manual for corrosion control of drinking water.

SECTION 4

EQUIPMENT DESIGN AND OPERATION

TEST SITE AND EQUIPMENT

The on-site treatment tests were conducted at the City of Seattle Fire Station No. 35, which is located in the Tolt distribution system in the north end of Seattle. The flow schematic of the on-site treatment plant is illustrated in Figure 2. As the water entered the fire station, it passed through the chemical feeding and mixing system and into the existing building plumbing system. Attached to the end of the existing plumbing system was the 1.9-cm-diameter old galvanized pipe test loop.

The pipe loop system was made from 10-year-old galvanized hot water pipe which was collected from the University of Washington. At the time of installation of the pipe loop, the pipe was highly tuberculated. The pipe loop was 8.5 m in length and contained 5 elbows. Pressure test gauges were located at the beginning and end of the loop for determination of headloss in the loop. A flow of 10.5 L/min through the loop was maintained using a throttling valve located at the end of the loop and was measured by a flow meter also at the end of the loop. The throttling valve was periodically shut off for the collection of 24-hour standing samples.

The chemical feeding and mixing system is illustrated in Figure 3. The chemicals were fed by two Liquid Metronix, Inc., diaphragm pumps. The chemicals used were hydrated lime [$Ca(OH)_2$] and sodium carbonate [$NaCO_3$]. Feed solutions of the full strength chemicals [170 g $CaOH_2$ / 151 L; 860 g Na_2CO_3 / 151 L] were mixed in 151 L plastic buckets. The feed solutions were then pumped from the solution buckets into the plumbing system just before the static mixers.

The chemical feed pumps were paced proportionally to the main flow volume using a Signet pump pulser. Flow was measured using a Signet paddle wheel flow sensor and self-powered flow meter.

CHEMICAL TREATMENT

The test treatment conditions were chosen to simulate average distribution system levels of pH and alkalinity during full-scale treatment start-up. Table 4 presents the target water quality for the test conditions.

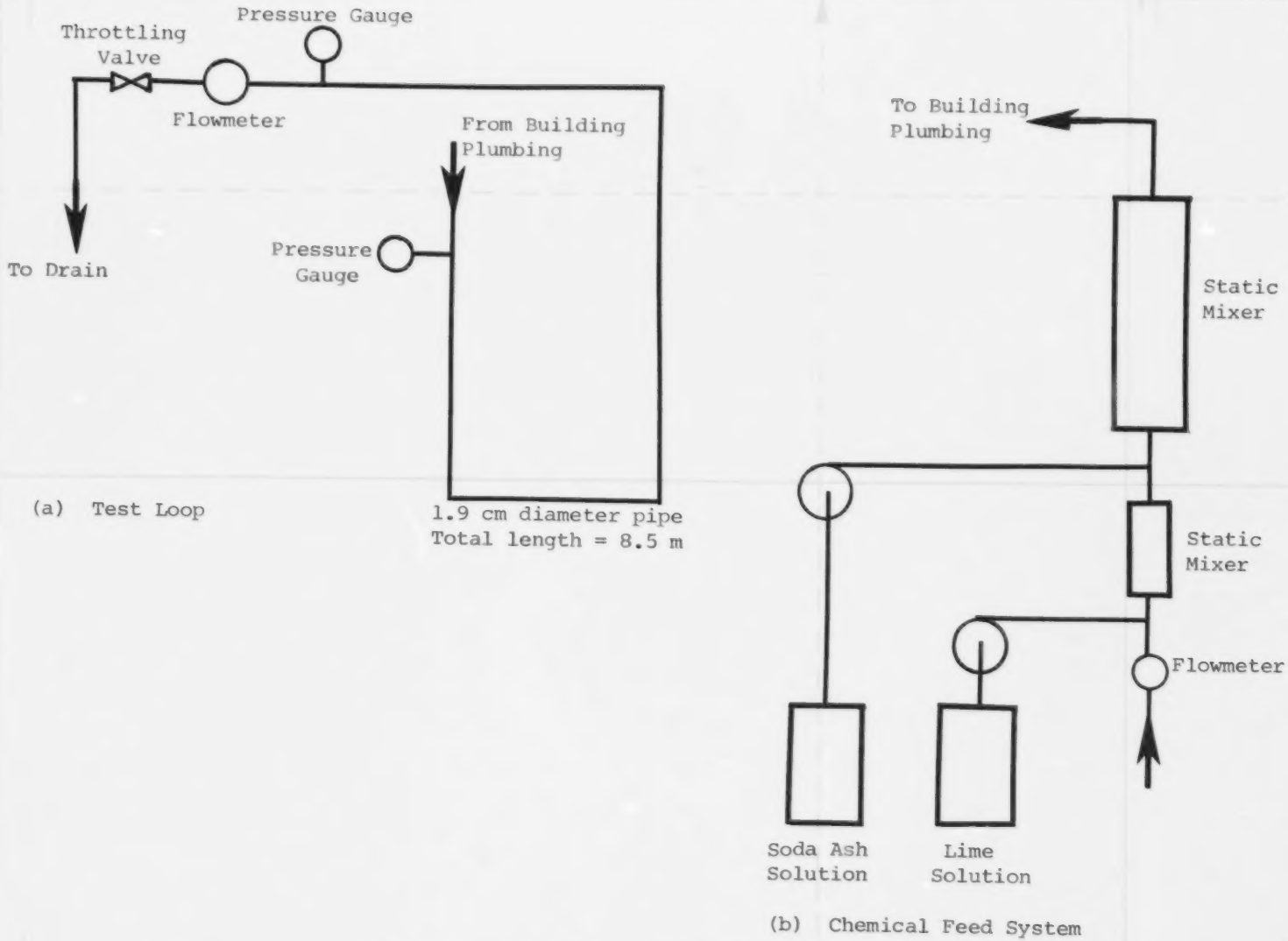

Figure 2. Pilot plant flow schematic.

TABLE 4. ON-SITE TEST TREATMENT CONDITIONS

Item	Phase I	Phase II	Phase III	Phase IV
pH	6.00	7.00	7.60	8.00
Alkalinity (mg/L $CaCO_3$)	2.0	9.0	8.0	14.0
Lime Dosage, CaO (mg/L)	0	0	2.00	1.70
Na_2CO_3 Dosage (mg/L)	0	7.42	6.40	9.00

The treatment phases listed in Table 4 were implemented in succession to simulate treatment start-up. Phase I, which lasted 106 days, was used to collect baseline data. Phase II (37 days), Phase III (18 days) and Phase IV (27 days) simulated the gradual increases in pH and alkalinity which will occur during full-scale treatment start-up.

SCANNING ELECTRON MICROSCOPY

Scanning electron microscopy was performed by the Materials Analysis Center of the University of Washington's Department of Mining, Metallurgical and Ceramic Engineering.

The Center has a Cambridge Mark IIA Scanning Electron Microscope (SEM) capable of 200 Angstrom resolution, which was used in the secondary electron emission mode. The instrument has useful magnification to 50,000X and is unique in that its large depth of focus allows unusual observation and photography of three-dimensional structures not possible with other microscopic techniques.

The SEM is equipped with the EDAX Energy Dispersive X-Ray Detector for elemental analysis from fluorine to uranium in the atomic table. Qualitative analysis in the SEM mode was conducted with spectra generation typically less than a minute.

SECTION 5

ANALYSIS AND PROCEDURES

SAMPLE COLLECTION AND ANALYSIS

General

The effects of treatment start-up were determined from standing and running samples and headloss determinations collected from the test pipe loop system. Standing water samples represented 24-hour stagnant water conditions in the pipe loop system. Running water samples were collected after a two-minute flushing at 10.5 L/min of the pipe loop system following the collection of the 24-hour standing sample.

Physical and Chemical Parameters

One-liter samples of 24-hour standing, running and control water were collected after each stagnation period. From these samples, 250 mL aliquots were immediately preserved (0.5% HNO_3 in Pyrex) for metals analysis.

Water from the 1-liter samples was analyzed for alkalinity, conductivity, turbidity, apparent color, total suspended solids and calcium concentration according to Standard Methods.[9] The metals analyzed and analysis techniques for the 250 mL aliquots are presented in Table 5. All analyses were conducted according to Standard Methods[9] and Methods for Chemical Analysis of Water and Wastes.[10]

TABLE 5. METALS ANALYZED AND ANALYSIS TECHNIQUES

Metal Tested	Analysis Method
Fe, acid hydrolizable	Flame Atomic Absorption Spectrophotometry
Zn, " "	" " " "
Cu, " "	" " " "
Pb, " "	Flameless Atomic Absorption Spectrophotometry
Cd, " "	" " " "
Na, " "	Flame Emission Spectrophotometry

Bacteriological

Water samples as well as tubercular incrustations were collected from the test pipe loop before corrosion treatment to determine the present microbial quality of Tolt distribution water in "old" galvanized premise plumbing. Regular monitoring of both these parameters was continued throughout treatment phases II, III and IV to observe any qualitative and quantitative changes occurring within the microbial population in the pipe loop due to corrosion treatment.

Water samples were collected twice per week in sterilized 1-L polyethylene bottles treated with 10% sodium thiosulfate. In general, water samples were analyzed within five hours after collection. Occasionally, the samples were refrigerated at 4°C if analysis could not be completed immediately, but all were processed within 12-18 hours. Due to high levels of turbidity, most notably in the standing water samples, three drops of a sterile 1% Tween 80 solution (a surfactant) were added to each 1-L sample bottle. The bottles were then thoroughly shaken in a 45° arc 25 times before dilutions were made.

Microbiological analyses included routine bacterial plate counts on Standard Methods agar[1] at 22-24° incubation for 6 days. Coliform counts were determined using the membrane filtering system (0.45 μm pore size membrane cartridge unit) and m-Endo LES agar.[9] Incubation was at 35 ± 0.5°C for 48 hours. In addition, other microbiological analyses were performed to determine other groups of organisms present in the water.

The microorganisms which were cultured on various selective enrichment media included iron and sulfur transforming organisms, specifically iron-precipitating and sulfate-reducing bacteria. In addition to water samples, tubercles were also examined for the presence of the above-mentioned organisms. For inoculation, the tubercles were manually ground in a sterile mortar, the samples weighed and the number of organisms recorded per gram of tubercle. For a brief description of the various selective enrichment culture media used, refer to Appendix A. A battery of 22 biochemical tests for identification of Enterobacteriacea and other gram-negative bacteria was used to identify isolates from the pipe loop system water.[11,12,13]

Verification of microbial growth in various enrichment culture tubes was conducted by means of direct microscopic examination of cellular morphology, as well as gram staining and biochemical testing. In addition, scanning electron microscopy was heavily employed (yielding 309 micrographs) for identification of microorganisms in the water samples as well as used for in-situ examination of tubercular incrustations on the interior pipe loop surface. X-ray energy-dispersive microanalysis was used to determine the elemental

---

[1]Standard Plate Count agar (Standard Methods, 15th Ed.). When the incubation temperature was lowered to 22-24°C from 35°C, microbial densities increased 40-90% after 6 days. It appears that the lower temperature is more conducive to the development of fresh water microorganisms whose natural habitat is in the range of 15-25°C.

composition of particulate matter in water samples as well as the chemical make-up of the tubercles.

Preparation of specimens for SEM and X-ray energy-dispersive micro-analysis generally was as follows:

> Water Samples: Standing, Running and Control samples: 20, 50 and 100 mL volumes of each sample were filtered through 0.2 μm Nuclepore filters; specimens were then fixed in an ice-cold solution of 2.5% (wt/vol) electron microscopy-grade glutaraldehyde in 50 mM monobasic potassium phosphate buffer, pH 7.0 for 30 minutes at 23°C. After fixation the specimens were gently washed twice in sterile prefiltered distilled water; dehydrated in an increasing ethanol concentration series (30, 50, 75, 85, 95, and 100% x 3), and transferred to a Freon 113 series before critical point drying (CPD). The specimens were then mounted on aluminum stubs with double stick tape and rendered electrically conductive by coating with vaporized carbon and 200-300 Å Au/Pd.
>
> Tubercles: Tubercles were carefully extracted from the pipe surface with a sterilized scalpel and fixed in an ice-cold solution of 2.5% (wt/vol) electron microscopy-grade glutaraldehyde in 50 mM monobasic potassium phosphate buffer, pH 7.0. After overnight fixation at 4°C, the tubercles were prepared in the same manner as the water samples; however, they were mounted to the aluminum stubs with silver collodial adhesive rather than tape. On some of the tubercles, partial dissolution of amorphous ferric iron was achieved by acidifying the samples with 1% oxalic acid for 30-45 minutes prior to the preparation for electron microscopy.[14]

Headloss

Headloss in the test pipe loop system was determined from water pressure and flow velocity measurements and the application of the Bernoulli equation. Water pressure measurements were made with pressure test gauges located at the beginning and end of the pipe loop system.

QUALITY CONTROL

Daily pH, alkalinity and flow measurements and adjustments, and apparatus maintenance were performed to provide quality control over the test conditions. To document lime and Na_2CO_3 feed, calcium determinations were performed daily and sodium determinations were performed twice weekly. All analyses were performed according to Standard Methods. Complete quality assurance data is presented in Appendix B.

In addition, short-term quality control tests were performed to measure the effects of flow fluctuations on chemical feed. Alkalinity, conductance, pH, calcium and sodium concentrations were measured for flows from 3.8 liters/min (L/min) to 57 L/min. These test results are also summarized in Appendix B.

SECTION 6

RESULTS AND DISCUSSION

GENERAL

The impact of treatment start-up on chemical, physical and bacteriological water quality was determined as described in Section 5. These tests were conducted on old galvanized pipe because negative impacts due to treatment start-up are more likely to occur on galvanized pipe systems than on copper pipe systems. Previous studies conducted by SWD have shown little or no improvements in iron corrosion and greater metals leaching in some situations as a result of treatment. Also, the effects of corrosion on galvanized pipe such as colored water, turbidity, stained fixtures and pipe deterioration, is much more apparent to the customer than copper corrosion.

THE EFFECTS OF TREATMENT START-UP ON CHEMICAL AND PHYSICAL PARAMETERS

Zinc Leaching

Figure 3 illustrates the effect of treatment start-up on 24-hour standing zinc concentrations. The target and actual pH of each treatment start-up phase is presented in Table 6. Upon initial treatment of Tolt water to an average pH of 7.11, zinc levels were reduced by approximately 61%. The pH was then increased to an average of 7.37. This was followed by a small spike in zinc leaching, which quickly dropped to approximately equal reduction levels. Upon full treatment to an average pH of 8.08, zinc levels increased to a final reduction of 50%.

TABLE 6. TREATMENT PHASES

Phase	Target pH	Actual Average pH	Duration
I	6.00	6.00	106 days
II	7.00	7.11	Day 0 to Day 37
III	7.60	7.37	Day 38 to Day 56
IV	8.00	8.08	Day 57 to Day 84

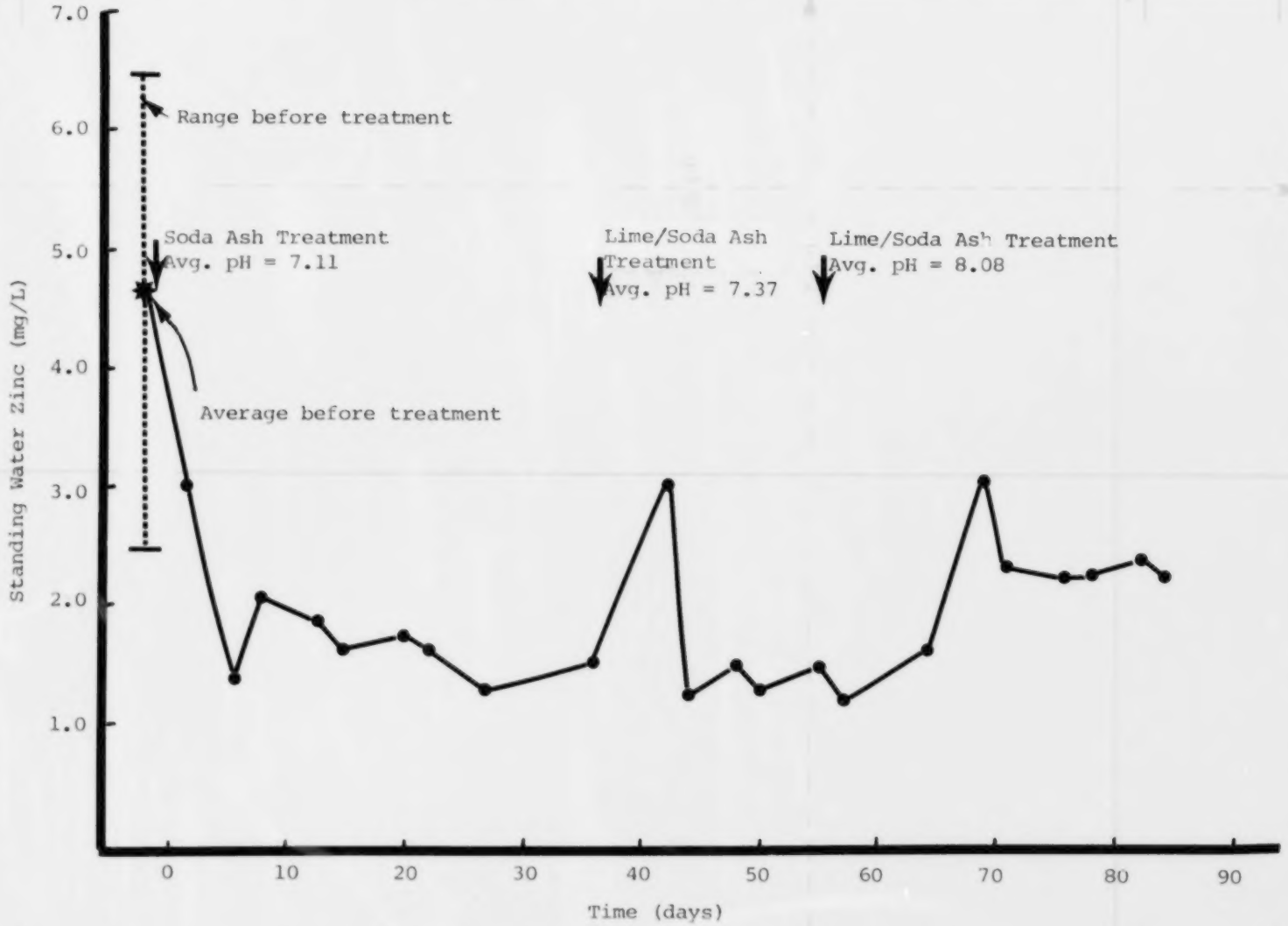

Figure 3. Zinc leaching from galvanized pipe.

The effect of pH on standing water zinc levels is presented in Figure 4. Figure 4 illustrates that zinc leaching in standing water decreases from pH 6 to approximately pH 7, and increases from pH 7 to pH 8. This data is consistent with the results from the Cedar and Tolt pilot tests. The Cedar tests showed an increase in zinc leaching with treatment, while the Tolt tests showed a decrease with treatment.

The data presented in Figure 4 supports the hypothetical zinc corrosion model detailed in Volume I, Cedar River Water Pilot Plant Study.[8] The model states that under standing water conditions, localized zinc corrosion occurs, creating local pH differences and a non-uniform corrosion film. At cathodic sites, dissolved oxygen is reduced thereby increasing the pH at those sites, and at anodic sites, the oxidation of zinc decreases the pH. At an initial pH of 8, the passivation film becomes unstable at both the anode and cathode, while at pH 7 the film is only unstable at the anode. The result is then greater zinc leaching at pH 8 than at pH 7.

As was also shown in the Tolt and Cedar pilot tests, zinc corrosion in running water was reduced with treatment. The running water metals results presented in Appendix C demonstrate that increased zinc leaching from pH 7 to pH 8 does not occur in running water. Instead, running water zinc levels were consistently reduced by approximately 72%.

Iron Leaching

Figure 5 illustrates the effect on treatment of iron leaching from old galvanized pipe. The results indicate an increase of approximately 38% over the average untreated standing water iron concentrations. The increased iron concentrations may be due to the diminished action of the zinc as a sacrificial anode. As the zinc is passivated, its sacrificial effect on iron is diminished thereby allowing iron to more readily corrode.

These tests agree somewhat with earlier tests which demonstrated only very slight corrosion rate reductions for iron. The Tolt pilot plant study showed increases with treatment of 33% and 10% in the weightloss and pitting rates of black steel, respectively. The Cedar pilot plant showed weightloss and pitting rate decreases of only 6% with treatment.

Appendix B presents running water iron leaching results. As with zinc leaching, running water iron levels were substantially reduced with treatment. Average running water iron reductions were approximately 61%.

Lead Leaching

Lead leaching results are presented in Figure 6. Standing water lead concentrations were reduced by 57% during treatment start-up. Running water lead levels showed no appreciable difference both before and after treatment.

Cadmium Leaching

Cadmium leaching results are presented in Figure 7. As with the zinc leaching results, standing water cadmium concentrations initially decrease

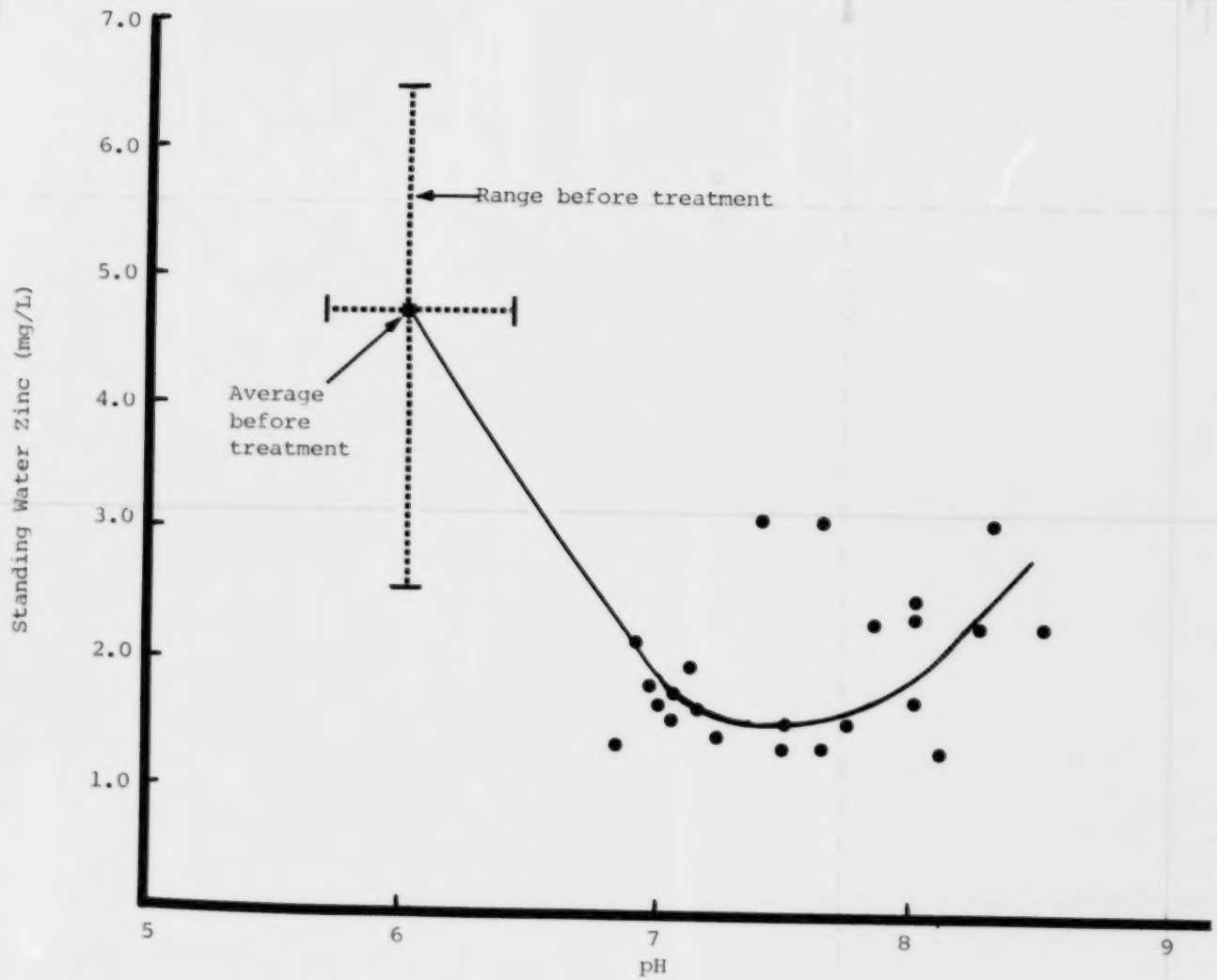

Figure 4. Zinc leaching versus pH.

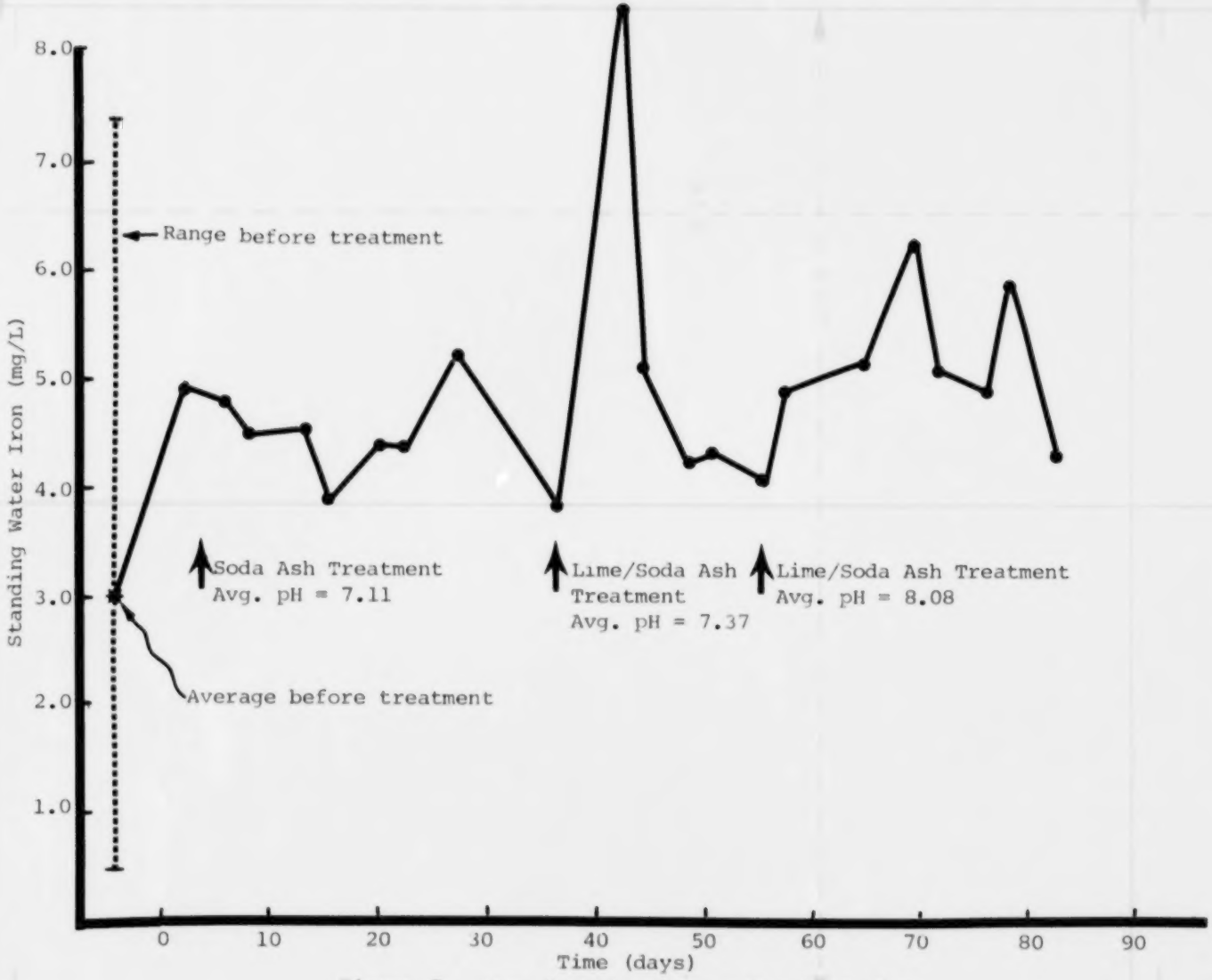

Figure 5. Iron leaching from galvanized pipe.

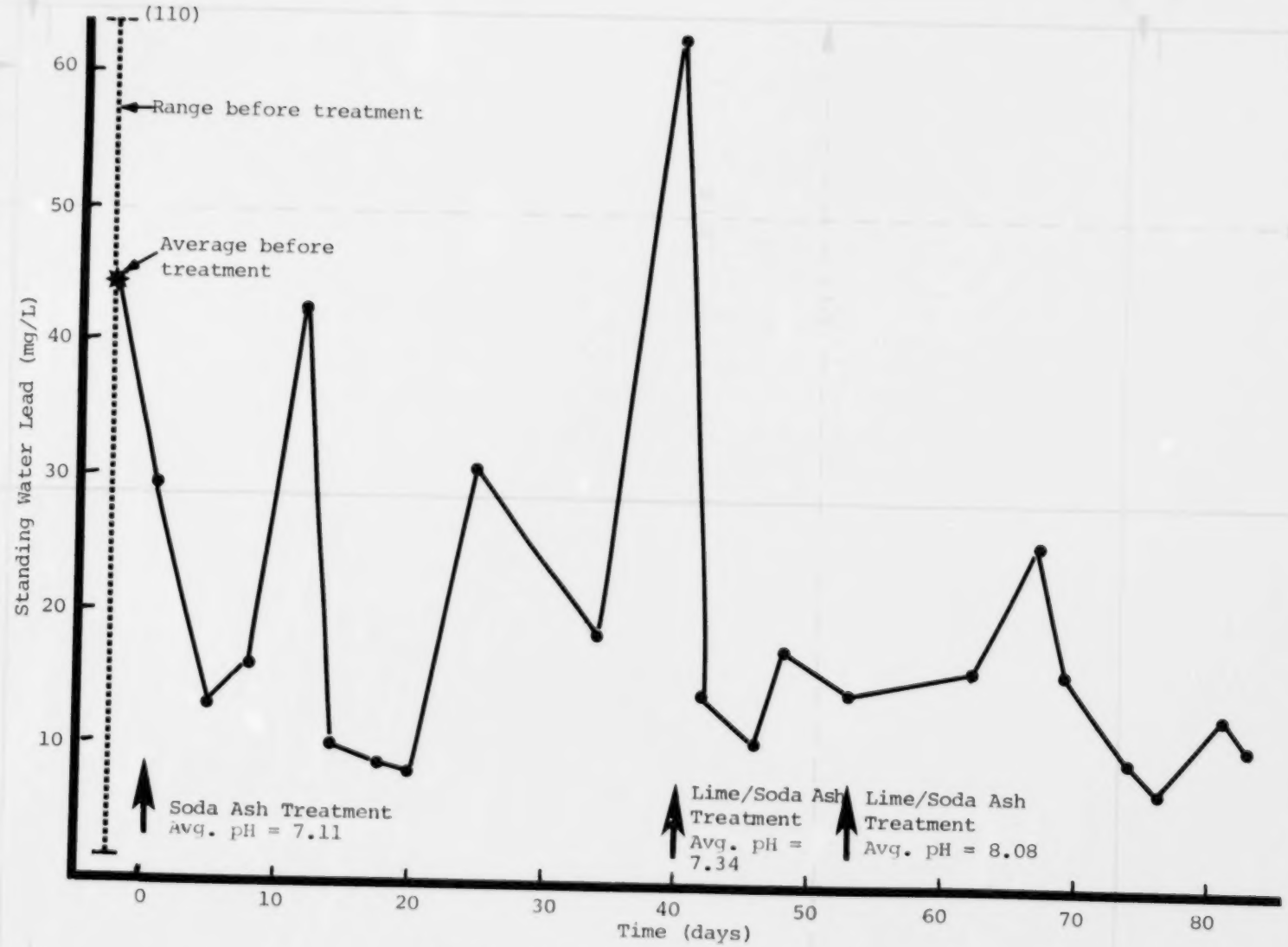

Figure 6. Lead leaching from galvanized pipe.

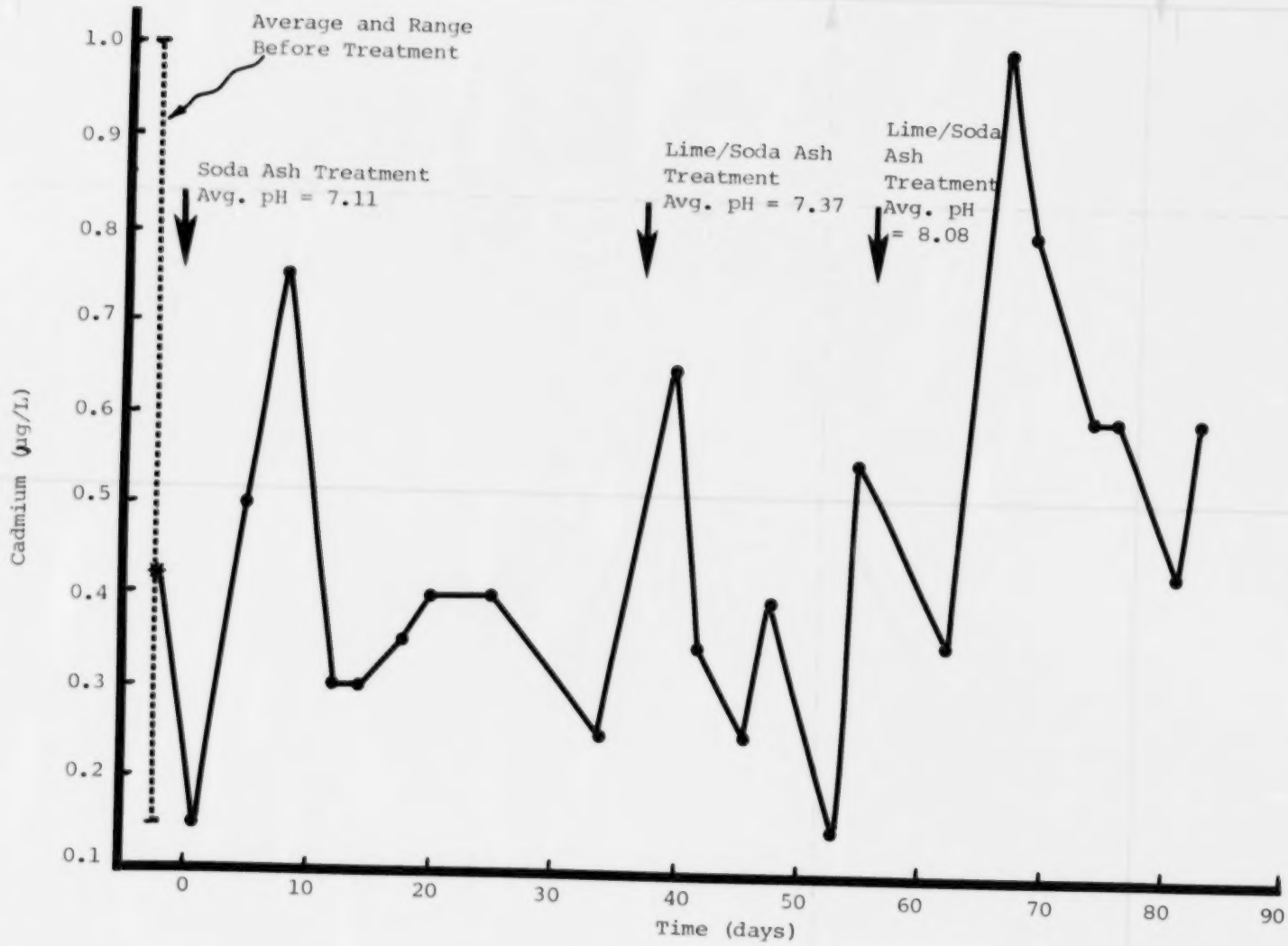

Figure 7. Cadmium leaching from galvanized pipe.

with treatment to pH 7, but then increase from pH 7 to 8. The Cedar[8] and Tolt[7] pilot studies also showed similarities between zinc and cadmium leaching.

The same type of corrosion mechanism is involved in cadmium corrosion as in zinc corrosion. Pourbaix[15] diagram for cadmium and zinc are very similar, showing unstable passivation films at low and high pH's for both metals.

Treated running water cadmium concentrations showed no appreciable change over untreated samples.

Copper Leaching

Although very little copper pipe was contained in the building plumbing system, copper concentrations increased in standing water compared to running water copper levels from Phase I through Phase IV. Copper leaching results are presented in Figure 8. Standing water copper concentrations were reduced by 53% from Phase II through Phase IV. Running water copper levels showed no appreciable difference before and after treatment.

Apparent Color

The apparent color of standing and running water responded similarly to treatment as did standing and running iron concentrations. Figure 9 demonstrates that standing water color levels increased by an average 23% with treatment over the untreated standing water conditions. The running water color levels remained essentially constant throughout treatment, with no deviation from the untreated running water level (Figure 10). Most of the apparent color is due to the iron concentration in the sample.

Turbidity

Figure 11 illustrates the effects of treatment start-up on 24-hour standing water turbidity levels. During initial treatment of Tolt water to an average pH of 7.11 (Phase II), turbidity levels increased slightly over those of untreated water, showing an average increase of 22%. With continued treatment of pH levels of 7.37 and 8.08, standing water turbidity increased by 57%.

Figure 12 illustrates the effects of treatment start-up on running water turbidity levels. All three pH levels displayed similar readings, with an average turbidity reading of 0.51 NTU. This is much less than the 24-hour standing water average turbidity of 15.0 NTU.

Total Suspended Solids

Figure 13 presents the effects of treatment start-up on total suspended solids standing water concentrations. Suspended solids concentrations were reduced by approximately 20% in standing water throughout the treatment start-up. This indicates that sloughing off of iron tubercles in pipes will not occur during full-scale treatment start-up.

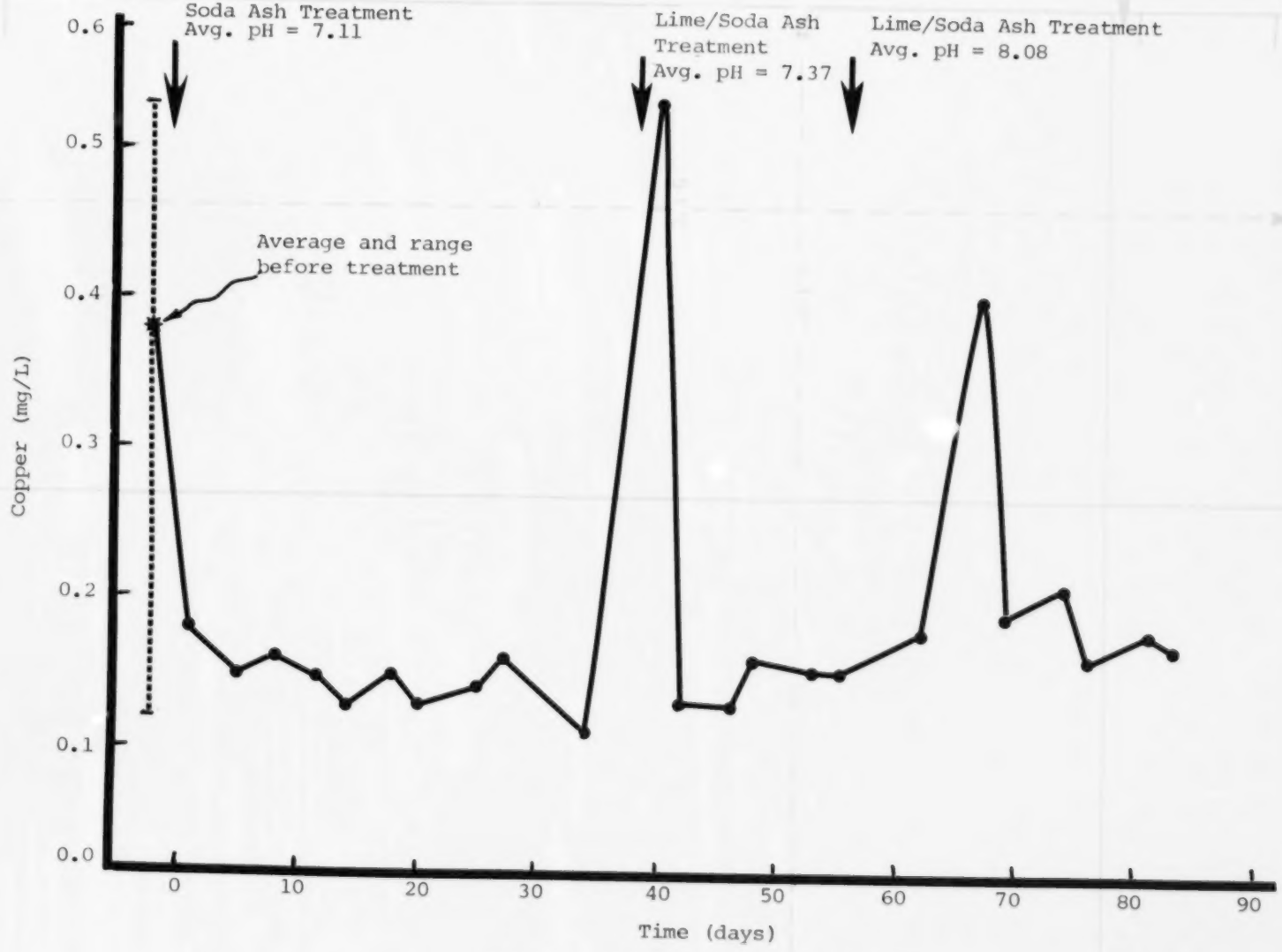

Figure 8. Copper leaching results.

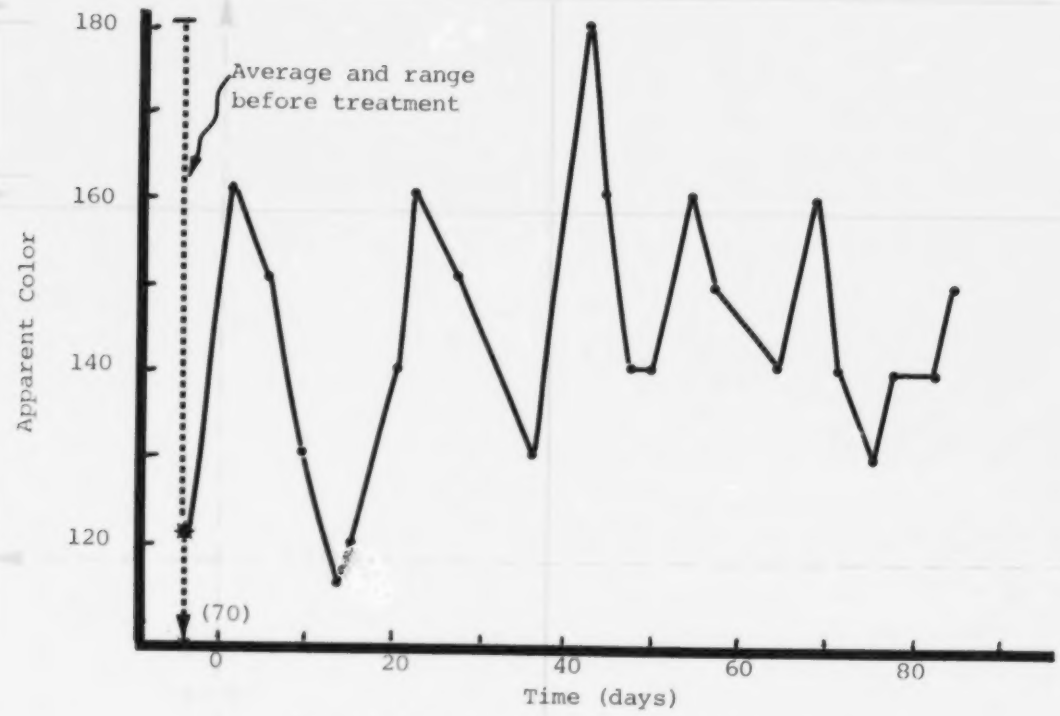

Figure 9. Standing water color versus time.

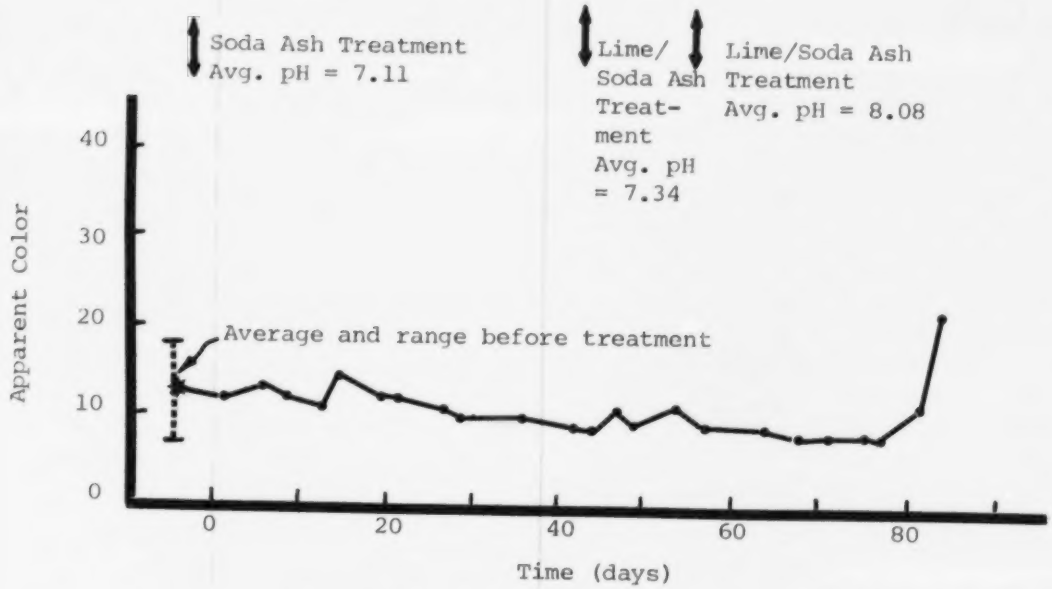

Figure 10. Running water color versus time.

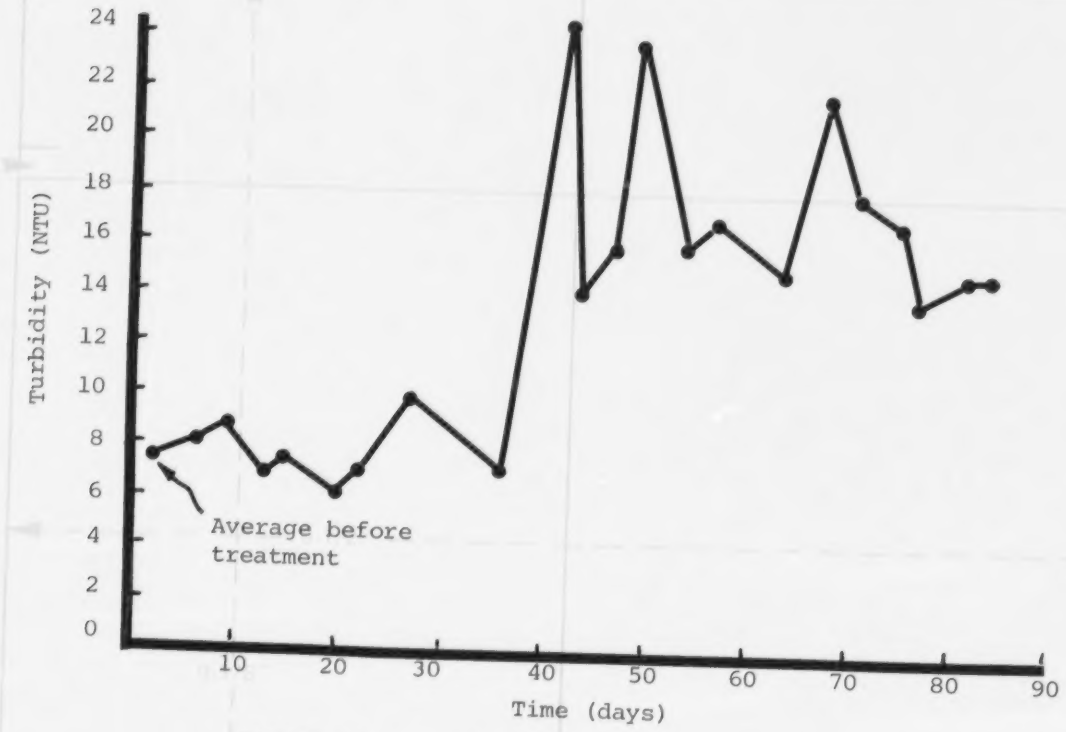

Figure 11. Standing water turbidity versus time.

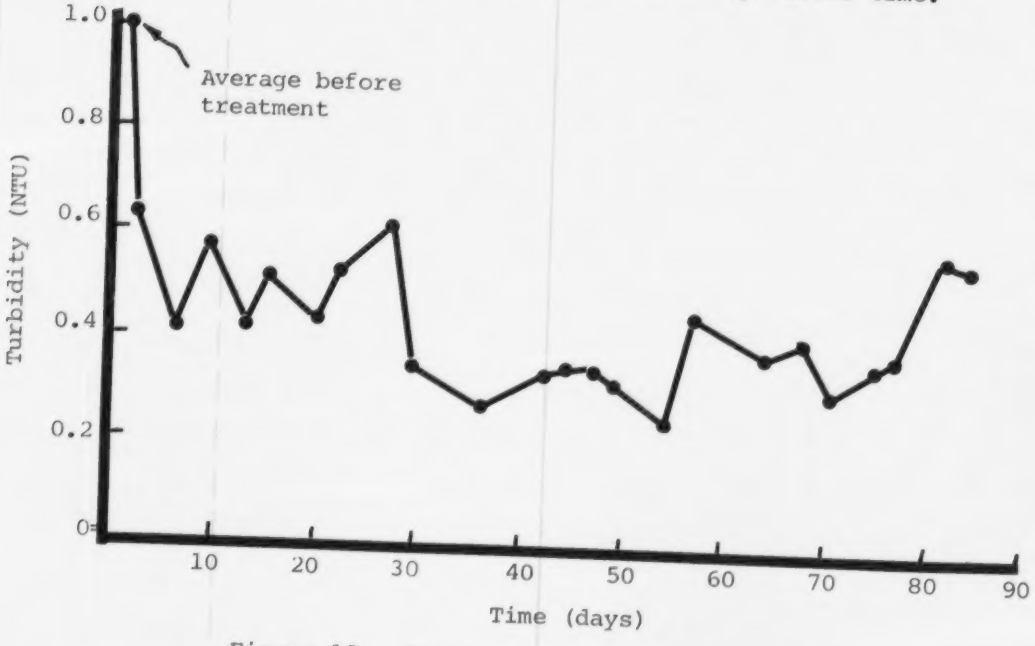

Figure 12. Running water turbidity versus time.

Headloss

Headloss was used as an indicator of tuberculation build-up in the pipe loop system. Figure 14 shows the increases in headloss with time both before and after treatment. The dashed lines in this figure represent the least squares fit of the data points before and after treatment, respectively. The slope of these lines is equal to the average rate of increase in headloss. Figure 14 demonstrates this rate was decreased by approximately 55% with treatment, which indicates that premature plugging of galvanized pipe will not occur because of corrosion treatment.

BACTERIOLOGICAL

Bacterial Characterization

Various organisms were observed in this study through the use of microbiological isolation techniques and chemical tests as well as SEM. These organisms included Desulfovibrio (a sulfate-reducer); Gallionella (an iron oxidizer); Pseudomonas aeruginosa and Flavobacterium spp. (coliform antagonists and opportunistic pathogens); Sphaerotilus (a sheathed bacterium); and filamentous bacteria. The results of the microbiological isolation techniques and SEM analyses are presented in Table 7. SEM plates are presented in Appendix D.

Many different species of diatoms and algae were also observed with SEM as well as species of Cyanobacteria (see Figures D-1 through D-3). Prosthecate bacteria, for example, Caulobacter spp. - budding, stalked iron bacteria (see Figures D-3, D-4, D-5, D-7) and Hyphomicrobium spp. were also observed. These were often found entwined with and attached to algal cells, while others were attached to various bacteria or inorganic debris (see Figure D-7).

The oxalic acid used in the preparation of some tubercles for SEM clearly dissolved the amorphous iron; however, the granular iron, partially crystallized, was not significantly reduced in number or size (Figure D-6). By these acid treatments, it was possible to demonstrate extracellular layers of fibrous material (Figures D-9 and D-10). The cells were not considerably plasmolyzed by the treatments. However, many cellular structures were still discernible owing to the presence of iron deposition.

Gallionella was shown to exist in pipe loop 24-hour standing water samples during Phases II-IV. It probably was present in Phase I as well, since water containing 0.2-0.3 mg/L of iron will almost always contain ferruginous bacteria, but in concentrations too low to be detected.[16]

Desulfovibrio increases slightly in pipe loop 24-hour standing water from Phase I through Phase III, then gradually began to decrease. The amount of sulfate-reducing bacteria present per gram of tubercle remained virtually the same both before and after treatment (see Table 7).

Several explanations may account for the results observed for Gallionella and Desulfovibrio. First, Gallionella oxidizes ferrous iron to hydrated ferric

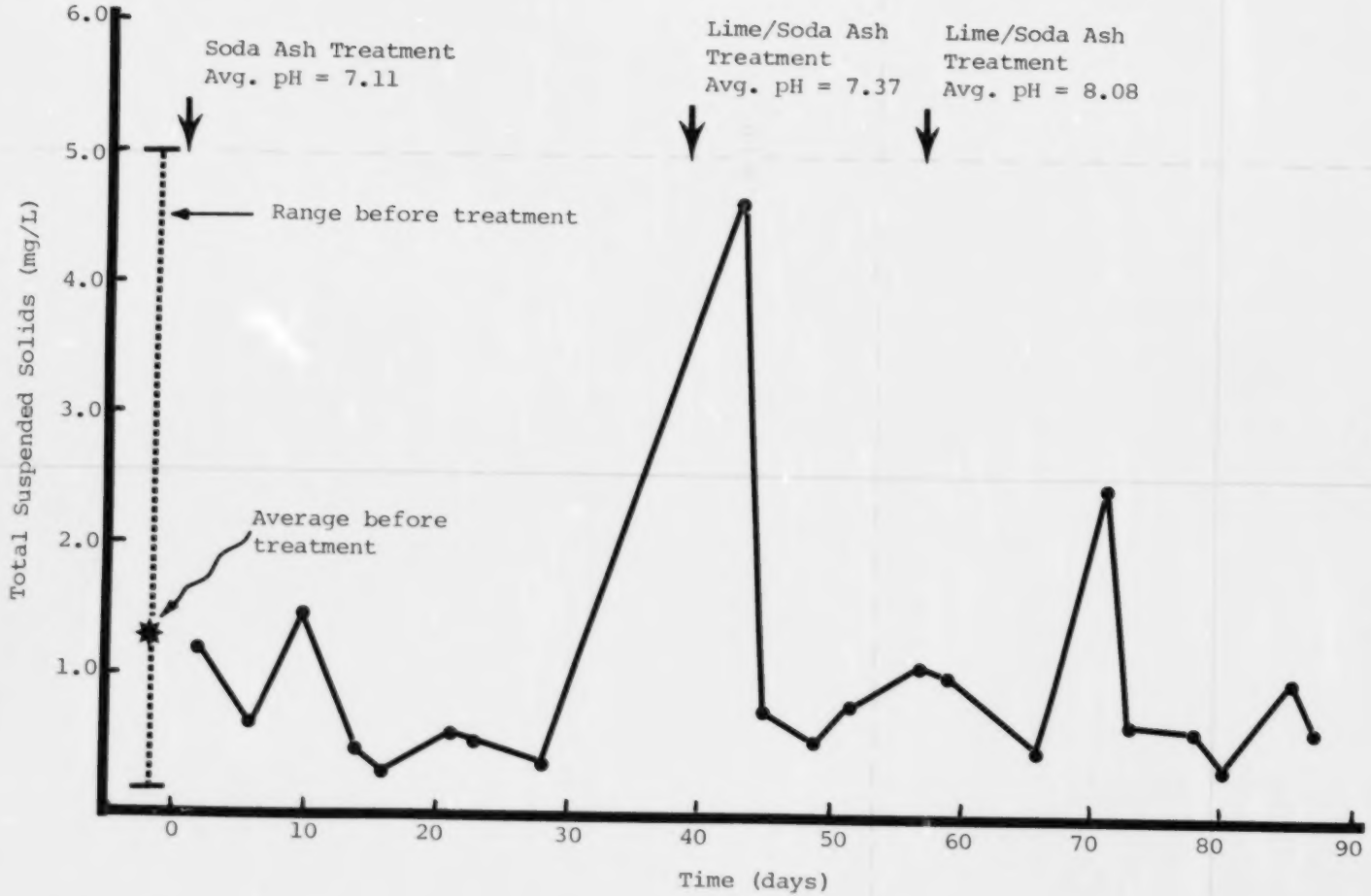

Figure 13. Total suspended solids versus time.

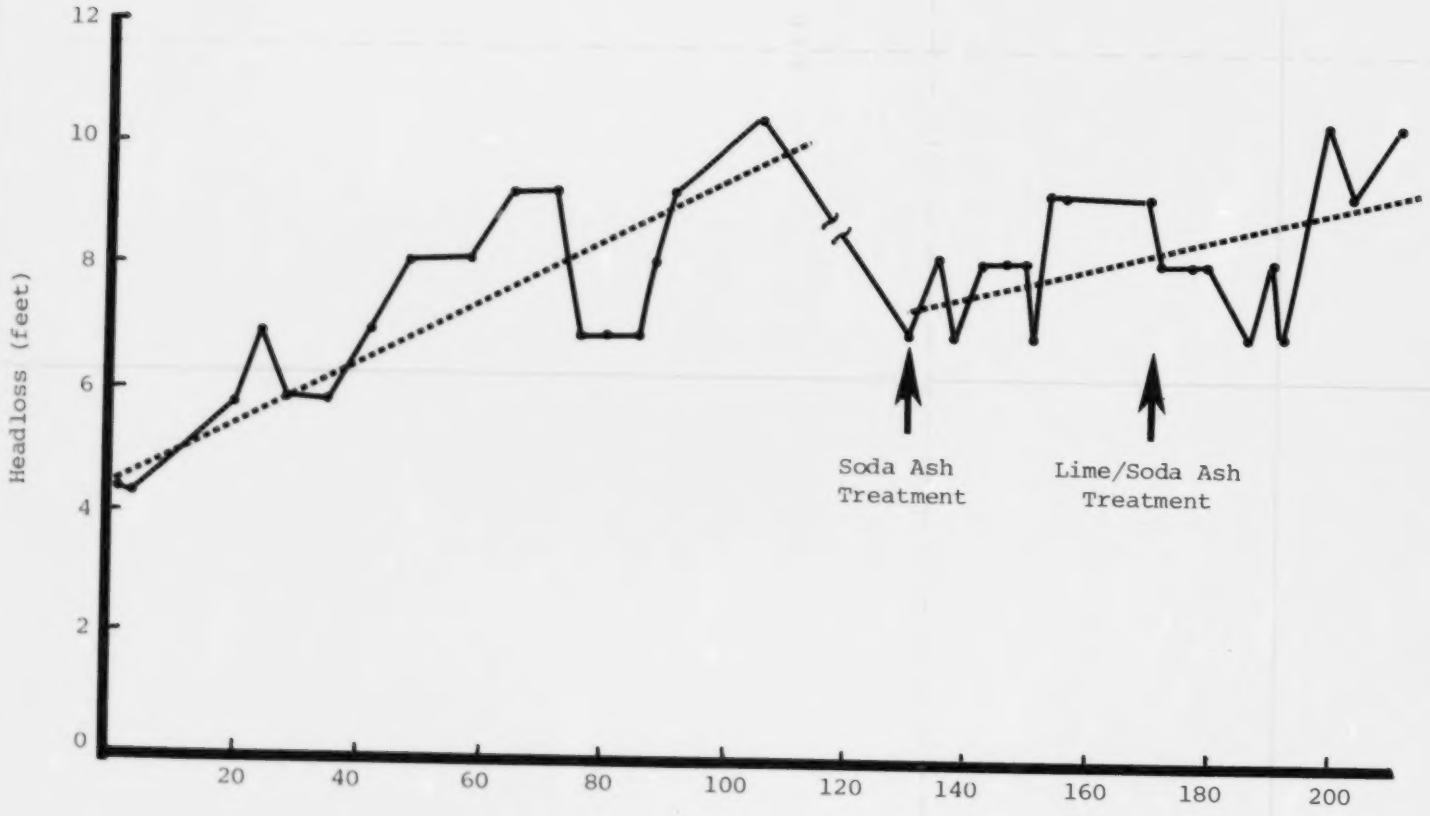

Figure 14. Headloss versus time.

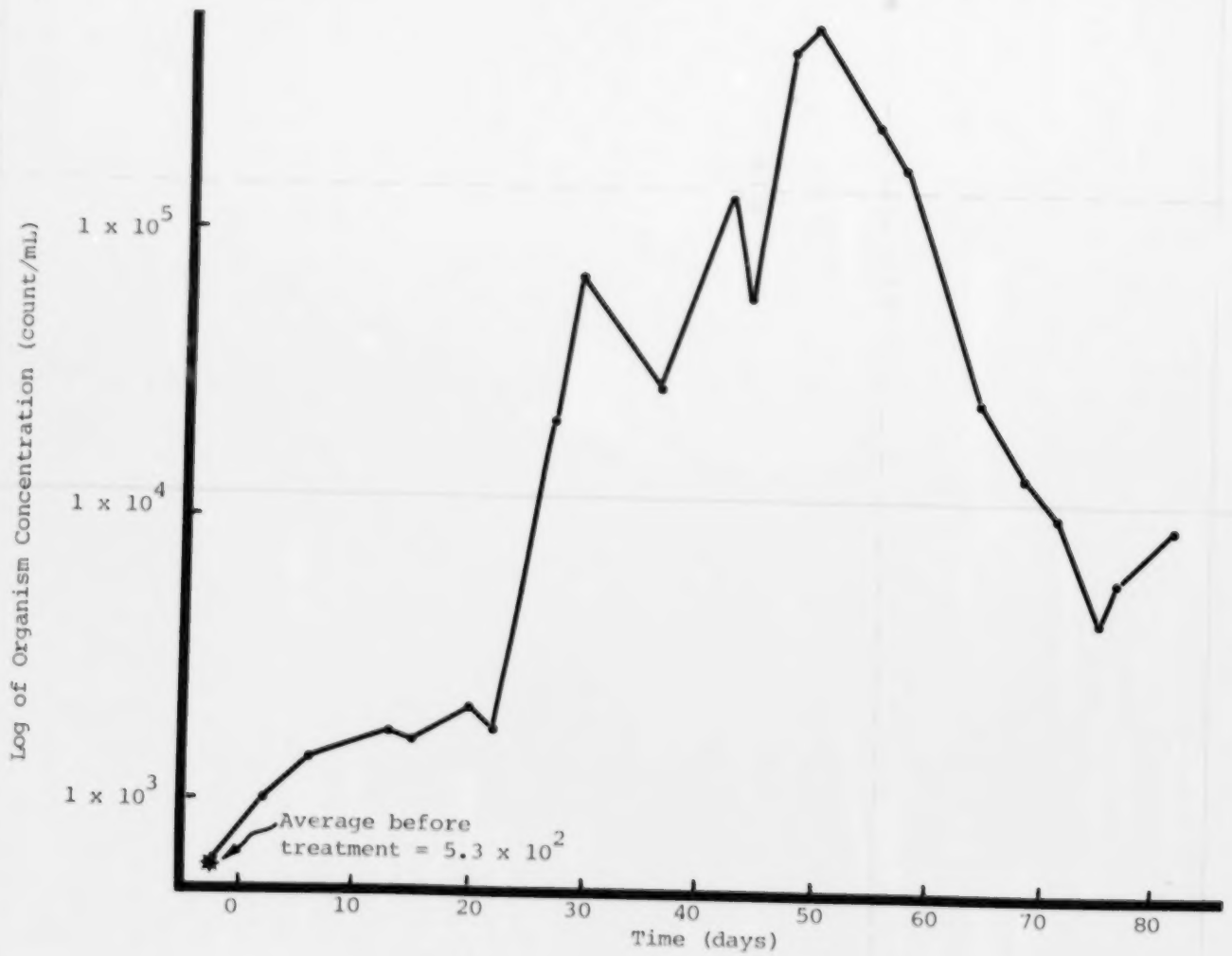

Figure 15. Standing water six-day standard plate counts versus time.

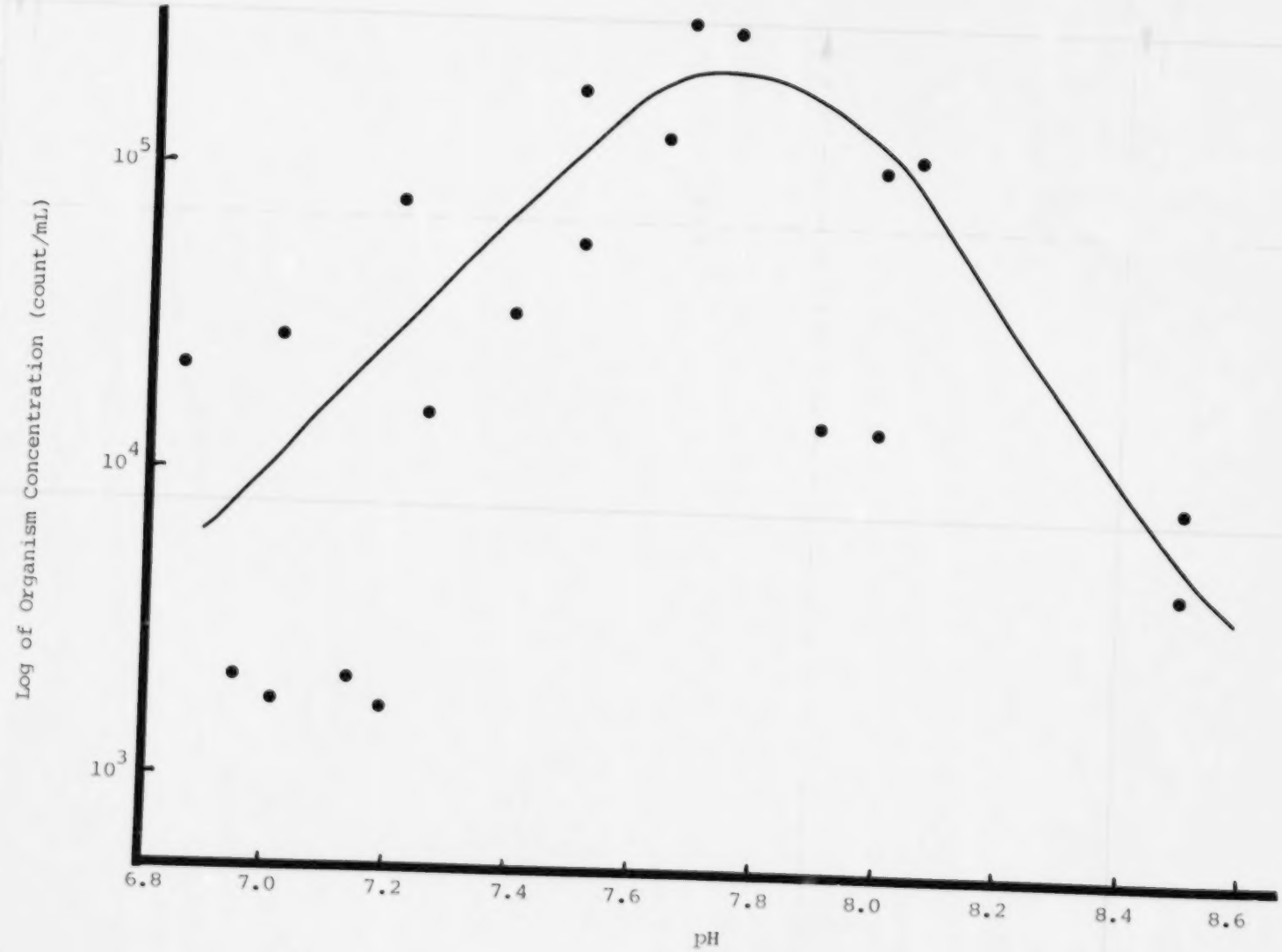

Figure 16. Standing water six-day standard plate count versus pH.

TABLE 7. BACTERIOLOGICAL ANALYSES OF CORROSION-RELATED MICROORGANISMS

PHASE	Total # H_2O Samples Collected	# of H_2O Samples Analyzed	Desulfovibrio Water (org/100 mL) Control	Desulfovibrio Water (org/100 mL) Standing	Desulfovibrio Tubercles† (org/gm)	Gallionella Water (org/mL) Control	Gallionella Water (org/mL) Standing	Gallionella Tubercles	Filamentous Organisms* Water (org/mL) Control	Filamentous Organisms* Water (org/mL) Standing	Filamentous Organisms* Tubercles
I	13	8	ND	$P^{a,b}$ 10	$P^{a,b}$ (1700)	ND	ND	$P^{a,b}$	ND	P^{b}	P^{b}
II	9	6	ND	$P^{a,b}$ 24	--	ND	$P^{a,b}$	--	ND	P^{b}	--
III	4	4	ND	$P^{a,b}$ 28	--	ND	P^{a}	--	ND	P^{b}	--
IV	9	6	ND	$P^{a,b}$ 18	$P^{a,b}$ (2400)	ND	$P^{a,b}$	$P^{a,b}$	ND	P^{b}	P^{b}

(continued)

P: Present.
NM: Not measured.
ND: Not detected, i.e., in low concentrations.
[a]Detection by direct isolation techniques.
[b]Observed by scanning electron microscopy.
*Possible organisms might include the Sphaerotilus-Leptothrix group and the Actinomycetes, etc.
†The amount of tubercular incrustations (grams) examined after Phase I and Phase IV was equivalent.

TABLE 7, Cont.

PHASE	Total # H_2O Samples Collected	# of H_2O Samples Analyzed	Caulobacter and Hyphomicrobium spp.			Diatoms
			Water (org/mL)			Tubercles (org/gm)
			Control	Standing	Tubercles	
I	13	8	P[b]	P[b]	ND	P[b]
II	9	6	P[b]	P[b]	--	--
III	4	4	ND	P[b]	--	--
IV	9	6	P[b]	P[b]	P[b]	pb

P: Present.
NM: Not measured.
ND: Not detected, i.e., in low concentrations.
[a]Detection by direct isolation techniques.
[b]Observed by scanning electron microscopy.
*Possible organisms might include the Sphaerotilus-Leptothrix group and the Actinomycetes, etc.
†The amount of tubercular incrustations (grams) examined after Phase I and Phase IV was equivalent.

hydroxide. Table 7 indicates an increase in standing water iron concentration of approximately 38% over the average untreated standing water iron concentration, thereby providing an increased amount of iron ions for microbial assimulation, and through oxidation, yielding insoluble ferric hydroxide.

As ferrous deposits increase, anaerobic conditions prevail at the metal surface and the microbial attack becomes more vigorous as a differential cell is formed.

Second, as the heterotrophic bacteria increased in number after Phase I (see Table 8), oxygen was consumed and anaerobic conditions were created near the pipe wall causing environmental conditions to change in favor of the growth of sulfate-reducers such as Desulfovibrio (see Table 7).

Bacteriological Quality During Treatment Start-Up

Standard plate count levels and coliform levels during treatment start-up are presented in Table 8. A definite increase was observed in the number of heterotrophic bacteria which can precipitate iron from solution. Many microbiologists searching microscopically for iron bacteria in iron precipitates have found the presence of aggregated bacteria encrusted with ferric hydroxide instead of the usual filamentous iron bacteria. Genera which contain species that have been found capable of precipitating iron from the salts of organic acids include Enterobacter, Bacillus, Pseudomonas, Serratia, Flavobacterium and Mycobacterium. The ferric hydroxide is apparently a waste product and iron salts are a necessary metabolite for these forms. Microorganisms may also produce a reducing environment by forming metabolic end products which can act as reductants of iron.[16,17,18]

Pseudomonas aeruginosa counts increased 47% from Phase I to Phase IV, while Flavobacterium spp. counts increased 24% during the same period.

Qualitatively, the number of diatoms observed by SEM appeared to increase substantially during Phase III and Phase IV, with many harboring assorted species of bacteria and varying amounts of organic debris (see Figures D-1 and D-2).

Figure 15 illustrates the effects of treatment start-up on 6-day standard plate counts. The highest counts/mL resulted between day 30 and day 60, i.e., starting the end of Phase II and continuing through the beginning of Phase IV.

One explanation for this occurrence may be that due to the prevailing environmental conditions such as pH, turbidity, and trace metal availability, changes in the microbial population occurred. This allowed certain microorganisms to predominate, such as filamentous bacteria or organisms which shed exopolysaccharide fibers, etc., thus creating protected habitats which can act as places of entrapment and harbor items such as corrosion products and provide a biological graveyard for cells of bacteria, algae and diatoms. In these areas, bacteria are often afforted protection from disinfectant action, especially in premise plumbing systems where there are often long standing times and non-existent chlorine residuals.[19] In addition, the sediments which can

TABLE 8. SIMULATED CORROSION TREATMENT START-UP

PHASE	Standard Plate Count (cfu/mL)*	Standard Plate Count (cfu/mL)†	Total Coliforms (cfu/mL)
Phase I (13 samples)			
Standing	60.0	5.30×10^2	< 0.5
Running	9.0	86.0	< 0.5
Control	1.0	3.0	< 0.5
Phase II (9 samples)			
Standing	2.23×10^3	1.51×10^4	9.0
Running	46.0	1.38×10^2	< 0.5
Control	< 0.5	2.0	< 0.5
Phase III (4 samples)			
Standing	1.48×10^5	2.55×10^5	1.0
Running	1.35×10^2	8.80×10^2	< 0.5
Control	1.0	7.0	< 0.5
Phase IV (9 samples)			
Standing	1.33×10^4	4.32×10^4	6.0
Running	1.20×10^2	4.13×10^2	1.0
Control	8.0	14.0	< 0.5

(continued)

*Incubated @ $35^{\circ}C \pm 0.5^{\circ}C$ for 48 hrs.

†Incubated @ $22\text{-}24^{\circ}C$ for 6 days.

TABLE 8, Cont.

PHASE	Turbidity (NTU)	Fe (mg/L)	Zn (mg/L)	Free Chlorine Residual (mg/L)
Phase I (13 samples)				
Standing	6.2	3.95	4.67	0
Running	1.2	0.420	0.310	0.20
Control	1.1	0.213	0.049	0.20
Phase II (9 samples)				
Standing	8.0	5.52	1.82	0
Running	0.58	0.166	0.13	0.15
Control	0.51	0.071	0.020	0.15
Phase III (4 samples)				
Standing	20.0	6.67	1.80	0
Running	0.44	0.140	0.096	0
Control	0.44	0.060	0.016	0
Phase IV (9 samples)				
Standing	17.0	6.00	2.13	0
Running	0.51	0.320	0.087	0
Control	0.41	0.080	0.023	0

*Incubated @ 35 $\pm$ 0.5^{o}C for 48 hrs.

†Incubated @ 22-24^{o}C for 6 days.

accumulate in these areas provide the organic nutrients to sustain microbial life and encourage selective regrowth of certain bacteria in the microbiota. Some of these regrowth events often contribute organisms that suppress detection of low-density levels of total coliforms (20), and other organisms capable of causing corrosion or taste and odor problems.

Figure 16 illustrates the effects of pH on 6-day standard plate counts of 24-hour standing water. Most of the standing water samples analyzed contained no free chlorine residual. For the samples with no chlorine residual, a steady increase in the number of microorganisms per mL was observed beginning at pH 6.8 and rising as the pH increased to approximately 7.8, then declining as the pH increased further to 8.5. One explanation for this may be the fact that the optimum pH for many of the microorganisms of concern in this study is between approximately 6.5 and 7.8.[21]

SUMMARY

Corrosion treatment start-up should have both negative and beneficial effects on water quality. The information presented above indicates that overnight standing water quality in old galvanized systems will not be substantially effected by treatment start-up. Some standing water quality parameters, such as iron concentration, color, turbidity, and bacterial concentration, increased with treatment and may present a problem during treatment start-up. It should be noted that this work represents a "worst case" condition and that the actual response of a plumbing system to corrosion treatment start-up will vary depending on the type, age and condition of the plumbing. It is expected, however, that running water quality will be improved during treatment start-up. Also, premature plugging of pipes will not occur because of treatment.

SECTION 7

RECOMMENDED START-UP PROCEDURE FOR FULL-SCALE CORROSION TREATMENT FACILITIES

GENERAL

The recommended start-up procedure for the full-scale corrosion treatment facilities has been based upon several considerations, including the effects on water quality, operator experience and training, and equipment reliability. The start-up procedure has been designed to minimize the adverse effects of treatment start-up on water quality at the customer's tap and to provide sufficient leeway for the plant operator to become acquainted with the plant's operation.

RECOMMENDED TREATMENT PLANT START-UP

The recommended timetable for full-scale treatment start-up at the Tolt and Cedar corrosion treatment facilities is presented in Table 9.

Start-up will begin at the Tolt treatment plant with lime treatment to pH 6.3, the lime will be brought up to its full treatment dosage of 1.7 mg/L and operated for one week in order to solve problems which may occur with the lime treatment system. A sodium carbonate dosage of 4.0 mg/L will then be added to provide approximately equal pH and alkalinity in the Tolt and Cedar systems. The system will be operated at this pH and alkalinity level for two weeks.

After two weeks of Tolt water treatment to approximate Cedar water quality levels, the Cedar treatment plant will start up and the Tolt treatment will increase simultaneously. Both the Tolt and Cedar will be treated to a pH of 7.5 and operated for two weeks. This will be achieved with a 1 mg/L CaO dosage at the Cedar and an additional 2 mg/L Na_2CO_3 dosage at the Tolt. After two weeks operation at pH 7.5, the two systems will be brought up simultaneously to full treatment dosages of 1.7 mg/L CaO in the Cedar water supply and 1.7 mg/L CaO and 9.0 mg/L Na_2CO_3 in the Tolt water supply.

TABLE 9. TOLT AND CEDAR CORROSION TREATMENT PLANT START-UP PROCEDURE

	Tolt				Cedar		
Day	Lime Dosage (mg/L) CaO	Sodium Carbonate Dosage (mg/L) Na_2CO_3	pH	Alkalinity mg/L $CaCO_3$	Lime Dosage (mg/L) CaO	pH	Alkalinity mg/L $CaCO_3$
1	0.8	0	6.3	3.4	0	7.2	16
8	1.7	0	6.6	5.0	0	7.2	16
15	1.7	4.0	7.1	8.8	0	7.2	16
29	1.7	6.0	7.5	10.7	1.0	7.5	17.8
42	1.7	9.0	8.3	13.5	1.7	8.3	19.0

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APPENDIX A

SELECTIVE ENRICHMENT CULTURE MEDIA

Media		Organism(s) Isolated
Reinforced Baars' Medium (Postgate's Medium B):[1]	pH 7.0, [$K_2 \cdot HPO_4$, 0.05%; NH_4Cl, 0.1%; $CaSO_4$, 0.1%; $MgSO_4 \cdot 7\ H_2O$, 0.2%; $Fe(NH_4)_2(SO_4)_2 \cdot 6\ H_2O$, 0.05%; sodium thioglycollate, 0.06%; ascorbic acid, 0.1%; yeast extract, 0.1% and sodium lactate, 0.35%] (freshly prepared on the day of experiment). The culture medium was added to a 60 ml bottle containing 30 ml of sample which was then filled to the brim and stoppered so as to exclude air. Incubation was at 28-30°C for 4-21 days.	Sulfate-reducers (Desulfovibrio)
Lewis Medium:[2,5,6]	pH 7.0, [Na_2SO_4, 0.15%; $K_2 \cdot HPO_4$, 0.05%; $Fe(NH_4)_2(SO_4)_2 \cdot 6\ H_2O$, 0.033%; $CaCl_2$, 0.01%; beef extract, 0.1%; peptone, 0.2%; sodium lactate, 0.35%; sodium ascorbate, 0.01% and $MgSO_4 \cdot 7\ H_2O$, 0.2%] (freshly prepared on the day of experiment). For pipe loop water, qualitative isolation of sulfate-reducers included streaking cultures on the Lewis medium solidified with 1.5% agar followed by incubation at 28-30°C in an anaerobic jar, and incubation of pour plate cultures at 28-30°C in an anaerobic jar, both under H_2. For quantitative enumeration of sulfate-reducers in tubercles and pipe loop water, the MPN series was used.	Sulfate-reducers (Desulfovibrio)
Ferrous Sulfide Agar:[3,5]	pH 6.6, [NH_4Cl, 0.1%; $K_2 \cdot HPO_4$, 0.05%; $MgSO_4 \cdot 7\ H_2O$, 0.02%; $CaCl_2$, 0.01% and $Fe(NH_4)_2(SO_4)_2 \cdot 6\ H_2O$, 0.5%]. Inoculated with a 1-5 ml suspension of Gallionella deposit. Incubated at 25°C for 18-36 hours.	Gallionella

(continued)

SELECTIVE ENRICHMENT CULTURE MEDIA, Cont.

Media		Organism(s) Isolated
Liquid Broth B_{12} Medium:[4]	pH 7.0; [glucose, 0.2%; peptone, 0.2%, $MgSO_4 \cdot 7 H_2O$, 0.2%; $CaCl_2$, 0.05%; $FeCl_2$, 0.01%; vitamin B_{12}, 0.01%]. A 10-ml sample was mixed with 10 ml of broth or 200 ml of sample was filtered through a 0.45 µm membrane filter. Incubated at 26°C for 48 hours. For identification of individual cells, the electron microscope was used.	Gallionella Sphaerotilus Caulobacter
M-PA:[5]	pH 7.1; [L-lysine HCl, 0.5%; NaCl, 0.5%; yeast extract, 0.2%; xylose, 0.125%; sucrose, 0.125%; lactose, 0.125%; phenol red, 0.008%; $Na_2(SO_4)_2$, 0.50%; $MgSO_4 \cdot 7 H_2O$, 0.15%; and ferric ammonium citrate, 0.08%]. (In an agar base, the following antibiotics were added: sulfapyridine, kanamycin, naladixic acid; and actidione) (membrane filter procedure used; plates incubated at 41.5 ± 0.5°C for 48 hours). For confirmation of typical and atypical colonies, milk agar was used and incubated at 35°C for 24 hours.	Pseudomonas aeruginosa

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APPENDIX B
QUALITY ASSURANCE DATA

Table B-1. Periodic Quality Control Analysis

Date 1981	Flow L/min	Untreated pH	Alk. mg/L $CaCO_3$	Cond. µmhos	Ca mg/L	Na mg/L	Treated pH	Alk. mg/L $CaCO_3$	Cond. µmhos	Ca mg/L	Na mg/L	Na_2CO_3 mg/L	CaO Dosage mg/L
1/6	10.5												
1/9	10.5												
1/12	10.5												
1/14			2.00	26.4									
1/15	10.5												
1/26	3.1												
1/27	10.2												
1/30	10.5												
2/3	10.5												
2/4	10.3		1.6	26.8									
2/10	8.8												
2/11	10.5		1.6	27.6									
2/18	10.5												
2/24	8.2												
2/25	10.5		2.0	25.4									
3/3	9.9												
3/4	10.3		2.2	26.7									
3/10	10.3												
3/11	10.5		1.68	25.3									
3/17	8.8												
3/18	10.9		0.8	23.8									
3/23	11.3												
3/24	10.6		0.9	24.0									
3/26	10.9		0.8	24.0									
3/31	10.2		3.4	24.6									
4/3	10.8		2.2	26.0									
4/6	10.5												
4/7	10.1		1.2	26.8									
4/13	10.5												
4/20	8.6												

(continued)

APPENDIX B
QUALITY ASSURANCE DATA

TABLE B-1, Cont.

Date 1981	Flow L/min	Untreated pH	Alk. mg/L $CaCO_3$	Cond. µmhos	Ca mg/L	Na mg/L	Treated pH	Alk. mg/L $CaCO_3$	Cond. µmhos	Ca mg/L	Na mg/L	Na_2CO_3 mg/L	CaO Dosage mg/L
5/13*	9.9						7.00	8.8	46.5			7.12	
5/14	9.6		1.8	27.7			7.49	13.2	43.7			12.5	
5/15	10.8		1.6	32.8			7.33	10.2	42.0			9.12	
5/17	11.0						7.40						
5/18	11.0						7.41						
5/19	10.5		1.6	27.4			7.42	8.6	42.0			7.42	
5/20	10.5						7.35						
5/21	10.5	6.15	2.2	27.0			7.41	9.4	39.0			7.63	
5/22	10.2	6.11	2.0	26.3			6.92	8.0	35.2			6.36	
5/25	10.2	6.10					7.12						
5/26	9.9	6.25	2.2	25.4			6.97	13.8	36.5			12.3	
5/27	19.5						7.15						
5/28	11.0	6.12	1.8	26.3			6.90	8.2	35.8			6.78	
5/29	11.0	6.15	1.4	25.2			7.01	8.2	34.9			7.21	
5/30	10.8						7.00						
6/1	10.6	6.05	2.2	28.5			6.95	8.6	35.6			6.78	
6/2	9.9	6.14	2.0	25.3			6.95	9.2	34.8			7.63	
6/3	9.6		2.0	26.0			6.93	9.2	35.6			7.63	
6/4	10.2	6.30	2.0	25.4			6.92	8.8	34.8			7.21	
6/5	11.0	6.11	2.4	24.8			6.89	10.2	37.4			8.26	
6/6	10.8	6.25					7.39						
6/8	10.8	6/20	2.0	25.8			6.85	10.6	40.3			9.12	
6/9	10.8	6.28	2.0	25.3			7.10	9.6	60.0			8.01	
6/10	11.0	6.32					7.20						
6/11	10.6	6.30	3.1	27.1			7.23	11.2	39.1			8.59	
6/12	10.2	6.20	2.2	25.9			7.24	11.2	49.7			9.54	
6/14	9.9	6.15					6.98						
6/15	10.1	6.10					7.00						
6/16	10.2	6.13	2.8	25.9			7.10	9.8	40.5			7.42	
6/17	24.9	6.15	2.2	23.9			7.05	10.8	36.0			9.12	

(continued)

APPENDIX B
QUALITY ASSURANCE DATA

TABLE B-1, Cont.

Date 1981	Flow L/min	Untreated pH	Alk. mg/L $CaCO_3$	Cond. µmhos	Ca mg/L	Na mg/L	Treated pH	Alk. mg/L $CaCO_3$	Cond. µmhos	Ca mg/L	Na mg/L	Na_2CO_3 mg/L	CaO Dosage mg/L
6/18	10.5	5.98	2.0	24.0			6.95	9.6	40.1			8.01	
6/19	10.5	6.12	2.2	25.3			7.05	9.0	37.4			7.21	
6/21	10.8	6.35					7.10						
6/22†	10.8	6.30					7.60						
6/23	10.8	6.20	2.0	25.0	6.0		7.63	8.2	34.0	10.2			2.35
6/24	10.5	6.10	1.8	26.1	8.0	0.99	7.40	7.6	35.6	11.0	2.62	3.75	1.68
6/25	21.5	6.10	2.0	27.9	7.0		7.50	7.6	37.5	9.6			1.46
6/26	10.5	6.10	2.0	26.4	8.0	0.94	7.10	7.6	36.4	9.2	2.63		0.67
6/28	19.3	6.10					7.23						
6/29	10.2		2.2	27.4	6.4		7.46	7.2	37.6	10.4			2.24
6/30	10.8		1.8	26.7	7.0	0.91	7.48	8.6	37.6	9.4	2.42	3.29	1.34
7/1	10.9	6.13	2.0	26.6	6.8		7.33	8.2	37.4	10.4			2.02
7/2	10.2		1.8	27.6	7.0	1.10	7.59	8.2	39.3	10.8	2.50	3.22	2.13
7/6	9.3	6.15					6.74						
7/7†	9.9		2.0	26.0	7.0	0.95	8.38	11.8	40.9	9.2	2.25	2.99	1.23
7/8	9.9	6.15	1.8	25.3	6.8		7.77	11.0	40.3	9.0			1.23
7/9	11.0	6.20	1.6	27.7	6.8	0.97	8.00	11.0	39.6	9.2	3.60	6.05	1.34
7/10	9.6	6.40					7.47						
7/12	10.3	6.42					7.52						
7/13	10.5	6.40	1.8	26.4	7.0		7.19	9.8	39.3	9.8			1.12
7/14	10.2	6.40	2.0	25.3	7.0		8.60	13.2	13.4	9.2			1.23
7/15	10.5	5.69	1.6	27.2	6.8		8.02	11.0	41.1	9.2			1.34
7/16	10.5	6.15	1.6	26.2	7.0		8.21	11.0	40.6	10.0	4.18	7.52	1.68
7/17	10.3	6.22	2.2	27.1	7.0		8.30	10.8	44.1	10.0			1.68
7/20	10.6	6.20	1.2	26.2	6.8		8.18	11.4	41.7	9.6			1.57
7/21	10.2	6.15	2.2	25.4	7.0	1.04	8.05	11.0	41.6	10.0	3.75	6.23	1.68
7/22	10.2	5.82	1.8	26.6	7.2		8.00	13.0	41.6	10.2			1.68
7/23	11.0	6.30	1.8	25.7	6.6	0.91	8.10	10.8	39.6	10.2	4.03	7.18	2.02
7/24	10.5	6.30					8.32						
7/26	9.8	6.30					8.04						

(continued)

APPENDIX B
QUALITY ASSURANCE DATA

TABLE B-1, Cont.

Date 1981	Flow L/min	Untreated					Treated						
		pH	Alk. mg/L $CaCO_3$	Cond. µmhos	Ca mg/L	Na mg/L	pH	Alk. mg/L $CaCO_3$	Cond. µmhos	Ca mg/L	Na mg/L	Na_2CO_3 mg/L	CaO Dosage mg/L
7/27	10.8	6.35	1.4	26.7	6.6		8.50	11.4	38.8	9.2			1.46
7/28	10.5	6.19	2.4	25.2	6.4	0.91	8.02	11.6	40.7	8.8	3.56	6.10	1.34
7/29	9.9	6.65	2.8	24.8			8.25	12.4	39.0				
7/30	10.5	6.30	2.0	24.3	6.4	0.93	8.10	12.0	39.2	9.4	3.45	5.80	1.68
7/31	10.5	6.45					8.35						
8/2	10.2	6.45	2.2	26.2			8.40	10.8	40.5				
8/3	10.3	5.95	2.2	25.2			7.99	10.8	39.0				
8/4	10.5	5.90	2.2	25.7	7.0	0.98	8.30	11.2	39.2	10.0	3.91	6.74	1.68
8/5			1.8	26.2	7.0	1.01		11.4	39.1	10.0	4.06	7.02	1.68

Table B-2. Flow Induced Chemical Feed Fluctuations

Flow L/min	pH	Cond. µmhos	Alk. mg/L $CaCO_3$	Ca mg/L $CaCO_3$	Na mg/L	CaO Feed mg/L	Na_2CO_3 Feed mg/L
Control	5.95	26.2	1.8	6.6	0.92	----	----
3.79	7.87	39.4	11.8	8.6	4.32	1.12	7.82
7.5	7.58	39.8	11.4	8.8	4.42	1.23	8.05
11.0	7.85	39.1	11.4	8.6	4.26	1.12	7.68
11.0	8.05	40.7	11.6	9.6	4.35	1.68	7.89
11.0	8.05	40.7	11.2	9.8	4.36	1.79	7.91
11.0	7.85	40.6	11.6	9.0	4.31	1.34	7.80
15.1	8.09	42.2	11.2	9.2	4.38	1.46	7.96
18.9	7.78	40.6	11.6	9.0	4.42	1.34	8.05
22.7	7.85	41.1	11.2	9.6	4.30	1.68	7.77
31.0	7.55	40.7	11.6	8.8	4.37	1.23	7.94
38.6	7.89	41.3	11.0	9.6	4.36	1.68	7.91
46.2	7.71	40.7	11.6	9.2	4.42	1.46	8.05
56.8	7.67	41.1	11.4	9.0	4.54	1.34	8.33

APPENDIX C

RUNNING WATER METALS RESULTS

Treatment	Iron mg/L	Lead µg/L	Zinc mg/L	Cadmium µg/L	Copper mg/L
Control	0.40	1.0	0.33	0.10	0.070
"	0.80	1.5	0.56	0.10	0.085
"	0.37	1.5	0.27	0.05	0.19
"	0.68	1.5	0.43	< 0.05	0.06
"	0.51	1.5	0.27	0.10	
"	0.22	1.0	0.24	0.10	0.065
"	0.13	2.5	0.30	0.10	0.12
"	0.24	1.5	0.26	0.15	0.06
"	0.51	4.0	0.35	0.15	0.09
"	0.32	1.5	0.33	0.10	0.17
"	0.19	1.0	0.22	0.10	0.09
"	0.26	1.5	0.30	0.10	0.295
Na_2CO_3	0.27	2.0	0.22	0.05	0.26
"	0.14	1.0	0.085	< 0.05	0.15
"	0.21	1.0	0.17	0.10	0.28
"	0.11	1.5	0.12	0.10	
"	0.11	1.0	0.12	0.10	0.06
"	0.24	1.5	0.19	0.05	0.14
"	0.16	1.0	0.12	0.05	0.15
"	0.22	1.5	0.12	< 0.05	0.15
"	0.10	1.0	0.05	< 0.05	0.055
"	0.10	< 0.5	0.08	< 0.05	0.060
$CaO + Na_2CO_3$	0.08	< 0.5	0.03	< 0.05	0.045
"	0.10	0.5	0.045	< 0.05	0.055
"	0.23	1.5	0.15	< 0.05	0.160
"	0.14	1.5	0.16	0.05	0.156
"	0.23	< 0.5	0.16	< 0.05	0.095
"	0.20	1.0	0.07	< 0.05	0.133
"	0.38	1.5	0.10	< 0.05	0.130
"	0.24	1.0	0.075	< 0.05	0.140
"	0.135	1.5	0.04	< 0.05	0.19
"	0.140	1.5	0.04	< 0.05	0.04
"	0.29	2.5	0.065	0.05	0.13
"	0.45	1.0	0.105	< 0.05	0.24
"	0.83	1.5	0.13	0.10	0.13

APPENDIX D

SCANNING ELECTRON MICROSCOPY ANALYSIS

Figure D-1. Diatoms in pipe loop water.
Note bacteria in diatom.

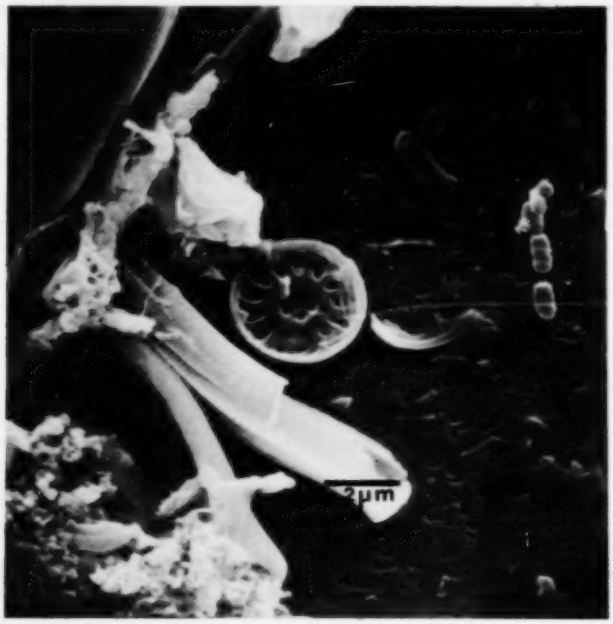

Figure D-2. Diatoms with algae and organic debris in pipe loop water.

Figure D-3. A budding Hyphomicrobium spp. seen with a specie of Cyanobacteria, a branching filamentous bacterium and a spherical diatom.

Figure D-4. A Caulobacter spp. isolated from culture media. Arrow pointing to a white crossband.

Figure D-5. A Caulobacter spp. as seen in pipe loop water.

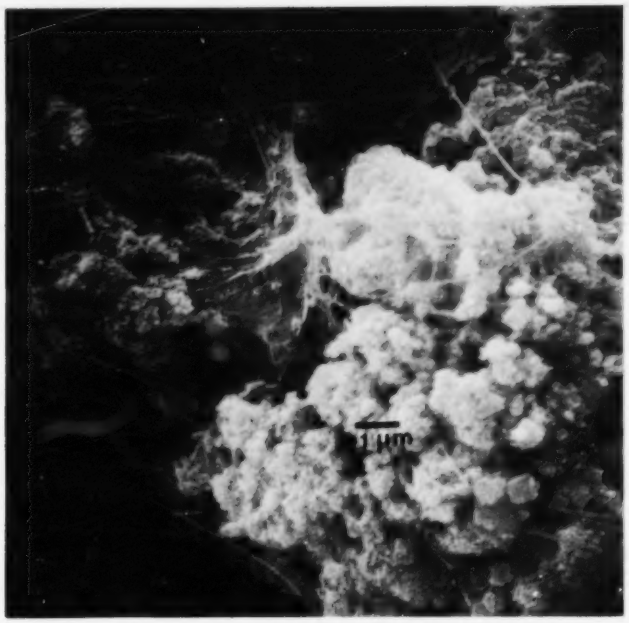

Figure D-6. Tubercular surface treated with oxalic acid; note the attachment of filamentous strands to the ferric hydroxide deposits.

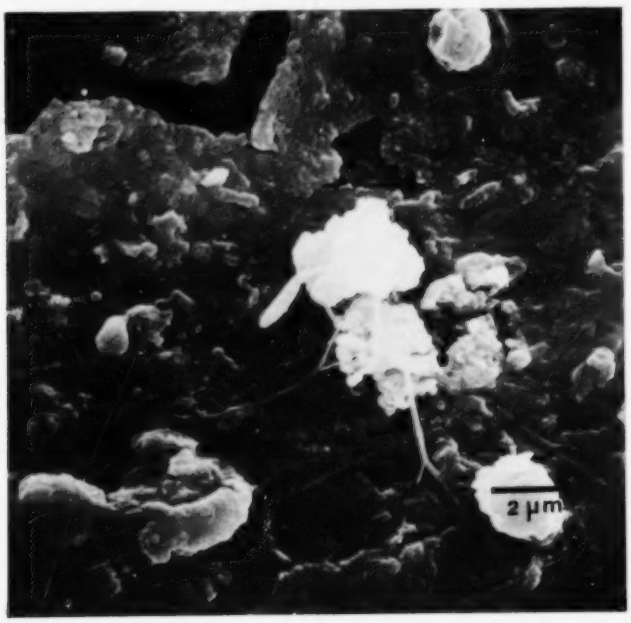

Figure D-7. A Caulobacter spp. found entwined with inorganic debris in standing pipe loop water.

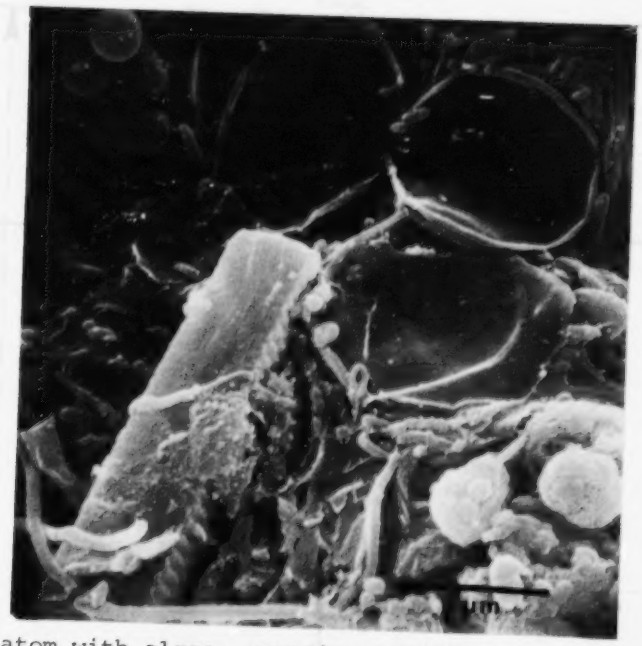

Figure D-8. Diatom with algae, organic and inorganic debris, and bacteria.

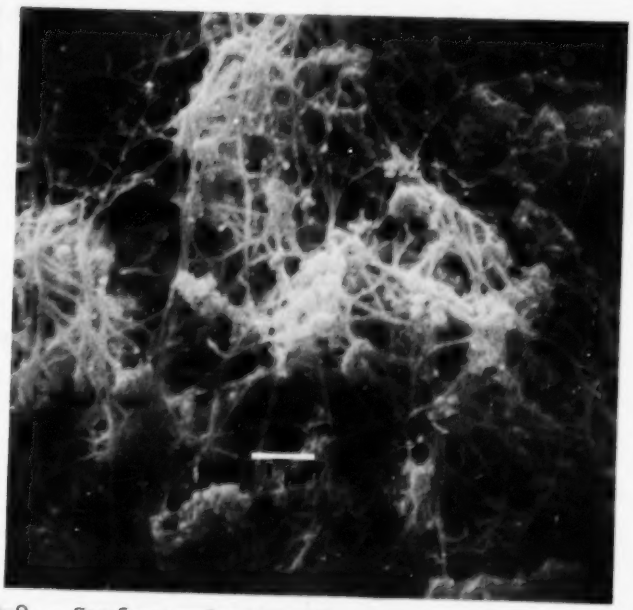

Figure D-9. Surface of tubercle showing filamentous growth.

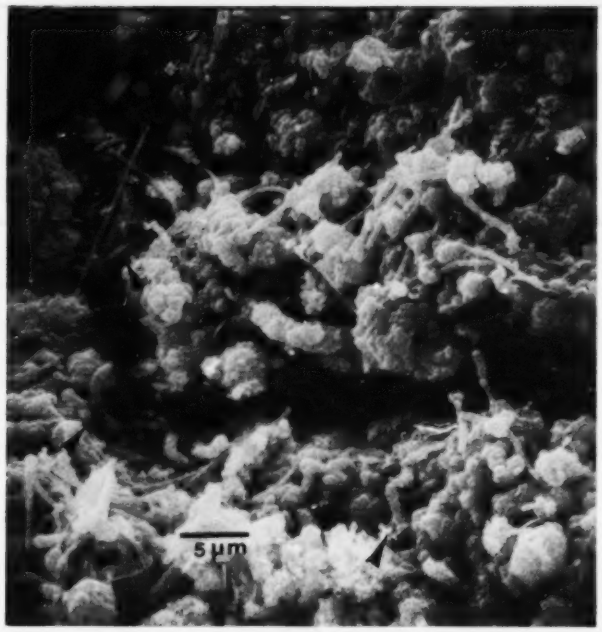

Figure D-10. Surface of tubercle.
Arrows directed at various bacteria.

Figure D-11. Surface of tubercle supporting bacterial growth - displaying heavy coating of ferric deposits.
Arrow pointing to a Caulobacter spp.

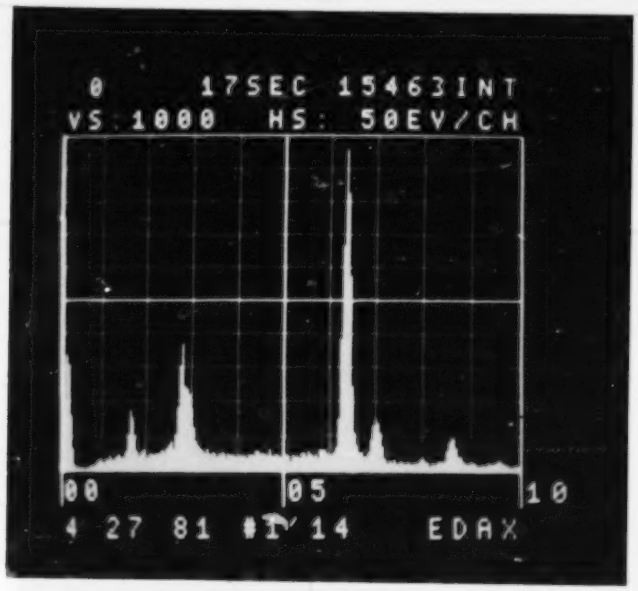

Figure D-12. X-ray energy-dispersive microanalysis of area outlined by the box in Figure D-11 showing major deposits of Mg (1.7o KeV), Fe (K_α line - 6.40 KeV and K_β line - 7.06 KeV), and Zn (K_α line - 8.64 KeV). X-ray counts were integrated over a period of 17 s.

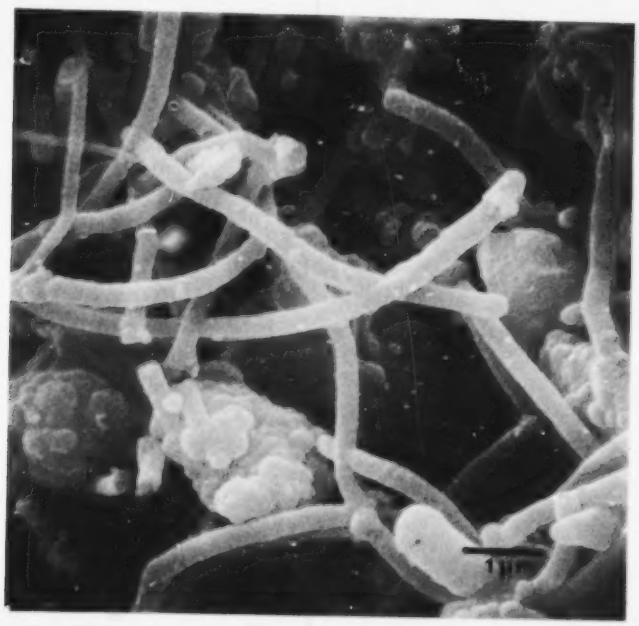

Figure D-13. Surface of tubercles displaying heavy ferric deposits.

Figure D-14. Surface of tubercles displaying heavy ferric deposits.

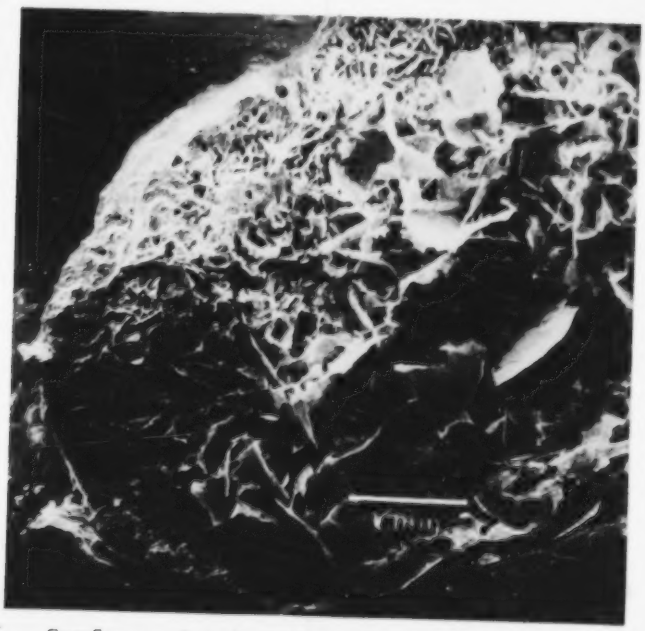

Figure D-15. Surface of tubercle next to interior pipe surface.

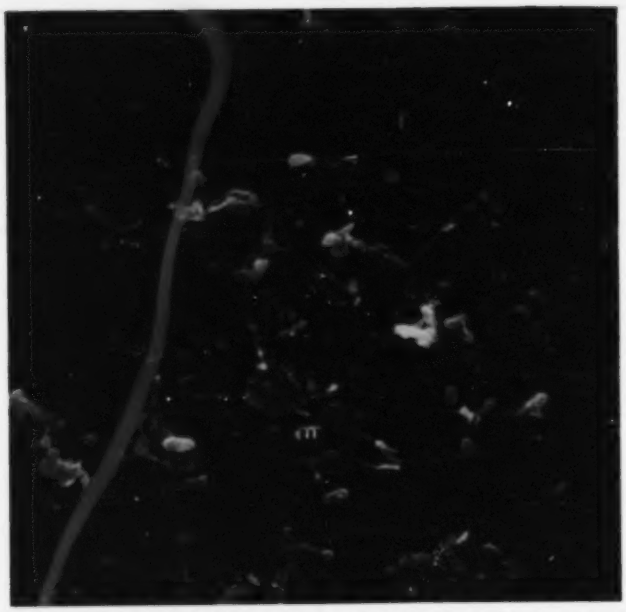

Figure D-16. Pipe loop standing water (50 ml) before corrosion treatment.

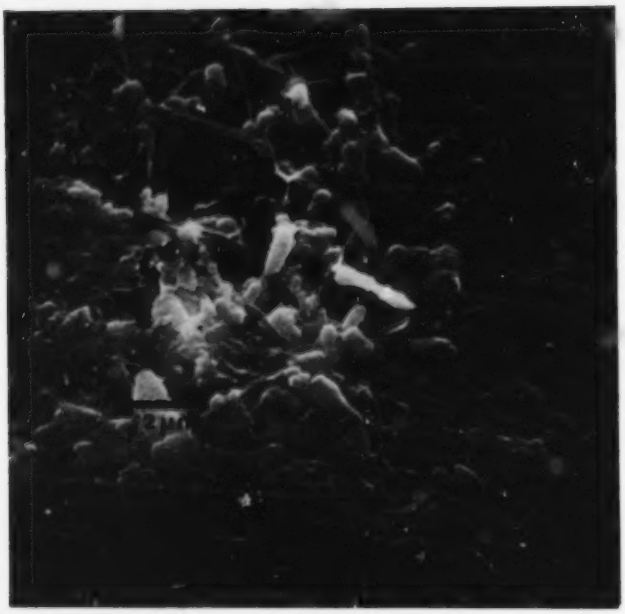

Figure D-17. Pipe loop standing water (20 ml) - Phase III of corrosion treatment.

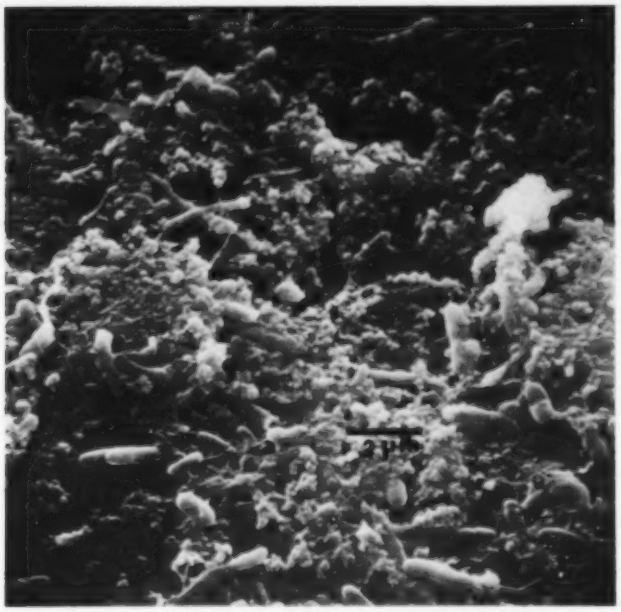

Figure D-18. Pipe loop standing water (20 ml) - Phase III of corrosion treatment.

Figure D-19. Pipe loop standing water (50 ml) - Phase IV of corrosion treatment.

APPENDIX E

POINT-OF-USE CORROSION INHIBITOR STUDY

SUMMARY

In order to determine the effectivness of point-of-use systems in reducing corrosion and corrosion-related problems, a questionnaire was sent out and a water quality survey was conducted.

The questionnaire was sent out to all known users of point-of-use corrosion control systems. Nearly all respondants indicated that they have experienced reductions in corrosion problems and were satisfied with the performance of their systems.

The water quality survey consisted of taking overnight standing hot, running hot, and cold water samples from systems which employ point-of-use systems. The results showed that the systems were effective in reducing corrosion-related deterioration in water quality.

INTRODUCTION

Background Information

General --

In 1974, the City of Seattle Water Department and the Seattle-King County Department of Public Health supported adoption of Ordinance 103095 that allowed chemical treatment of hot water systems for control of corrosion. This ordinance, plus amendments made in 1976, applies to systems within the City limits but does not pertain elsewhere in the County. Treatment of cold water systems was not allowed at that time because it was the hot rather than the cold water piping systems that were experiencing acute economic and aesthetic problems related to corrosion. In addition, the health officials were wary about the safety of such treatment systems and felt that should a problem develop, fewer people would be drinking the water from the hot water taps as opposed to the cold water.

The Need for Point-of-Use Treatment Systems --

The users who may need treatment of hot and/or cold water systems in addition to the Water Department's treatment are the industrial and commercial customers who have existing galvanized pipe that is not blocked by tuberculation and is still structurally sound. The long detention times of water in large buildings that are plumbed with galvanized pipe will continue to cause

rusty water problems even after the City's treatment program has been initiated, although at a reduced rate when compared to the existing situation. Point-of-use treatment may reduce the rate of corrosion even further and may prolong the life of the pipe. Although much of the costs of corrosion cannot be recovered, customers may be able to save money in corrosion costs if they were allowed to treat cold as well as hot water systems. In summary, the point-of-use treatment systems could complement the SWD program and could potentially reduce rusty water and prolong the life of piping.

Kennedy Pilot Tests --

The point-of-use treatment of hot water systems normally involves addition of polyphosphates or silicate inhibitors. Suppliers and users indicate that some of the chemicals will remove part of the rust tubercles and will then lay down a coating to protect the pipe. The consultant, Kennedy Engineers, tested similar chemicals in pilot testing and found them to be quite effective at reducing corrosion. They were not selected as the primary chemicals for use in the general water supply system either because of their high cost, their algae growth potential in open reservoirs or some other reason that made them unsuitable for use in the unique Seattle distribution system.

Objectives of Study

The following are the objectives for the point-of-use systems study:

1. Determine the effectiveness of point-of-use systems in reducing corrosion and corrosion-related problems.

2. Determine if the systems are or can be made to operate safely.

Scope of Work

The scope of work included:

1. Development of a Questionnaire;

2. Use of Water Quality Survey.

ANALYSIS AND PROCEDURES

Questionnaire

A questionnaire was sent out to all the known users of hot water point-of-use corrosion control systems. The questionnaire was designed to monitor the opinion of users regarding the safety and effectiveness of their point-of-use treatment systems.

Water Quality Survey

The water quality survey consisted of taking overnight standing hot and running hot and cold water samples from systems which employ point-of-use

corrosion treatment. In each system sampled, the sample collection point was located at the furthest accessible tap from the chemical injection point in order to provide a "worst case" condition.

For the sampling procedure, the standing hot water sample was collected first. Standing time was approximately 24 hours. The hot water was then flushed at about half of maximum flow for two minutes before the collection of a hot running water sample. The running hot water sample was intended to represent the average water quality which the customer receives. A cold water sample was then collected from the sample location after five full minutes of flushing to represent water quality in the watermain.

All samples were collected in one-quart cubitainers. A 240 mL alequot was poured off into pre-acidified metals sample bottles (0.5 HNO_3 in Pyrex) immediately after collection. The samples were placed on ice and taken to the laboratory for analysis.

Water quality parameters measured for each sample included:

a. Acid hydrolizable metals: Pb, Zn, Fe, Cd, Cu

b. Silicate or phosphate concentration

c. pH

d. Aesthetics: Color, turbidity

e. Specific conductance and alkalinity

All analyses were conducted according to Standard Methods and Methods for Chemical Analysis of Water and Wastes.

RESULTS AND DISUCSSION

Questionnaire

A summary of the responses to the questionnaire, which was sent out to all known users of hot water point-of-use systems in the city of Seattle, is presented in Table E-1. Eighteen (18) of 23 users of these systems (78%) returned the questionnaire. This represents a total of 54 individual point-of-use hot water systems. The results of the questionnaire shows that nearly all users of these systems experienced reductions in corrosion problems and were satisfied with the performance of the system.

Water Quality Survey

General --

The results of the water quality survey are summarized in Table E-2. Table E-2 also lists the average Cedar and Tolt 24-hour standing water quality conditions for single family residences. These values are presented in order to provide a comparison for the point-of-use corrosion inhibitor systems.

TABLE E-1. RESULTS OF POINT-OF-USE HOT WATER CORROSION TREATMENT SYSTEMS QUESTIONNAIRE

Name of Owner	Number of Systems	Length of Treatment	Water Supply	Treatment Chemical	Operational Problems	Type of Pipe
Clise Agency	1	2 yrs	Cedar	Silicate	No	Galvanized.
Harsh Investment Co.	4	1½-2 yrs	Cedar	Phosphate	No	Mixed galv. & copper / Replace copper.
Westlake Developers	1	3½ yrs	Cedar	Silicate	No	Mixture (copper & galvanized).
Medical-Dental Bldg	1	3 yrs	Cedar	Silicate	No	Copper (formerly galvanized).
Vance Corp.	2	3 yrs	Cedar	Phosphate	No	Galvanized.
Rainier Bank	1	3 yrs	Cedar	Silicate	No	Mixture (copper & galvanized).
C. K. Galland Home	1	-	Cedar	Silicate	No	New bldg copper; old bldg galv.
Magnolia Ct. Apts.	1	3 yrs	Cedar	Silicate	No	Mixture (copper & galvanized).
Shannon Condo. Assoc.	1	4 yrs	Cedar	Silicate	Yes	Mixture (copper & galvanized).
Leith Apts.	2	3 yrs	Tolt	Phosphate	No	Galvanized.
Sander Building Corp.	1	2½ yrs	Cedar	Silicate	No	Mixture (copper & galvanized).
Melrose Co-Op	1	5 yrs	Cedar	Phosphate	No	Galvanized.
America West Corp.	2	5 yrs	Cedar	Phosphate	No	Galvanized.
Unico Properties	2	½ yr	Cedar	Silicate	No	Copper/Galvanized.
University Plaza	1	1½ yrs	Mixed	Phosphate	No	Mixture (copper & galvanized).
Seattle Housing Auth.	30	3-5 yrs	Cedar/Tolt	Phosphate	Yes	Mixture (copper & galvanized).
Laurelhurst Apts.	1	2 yrs	Tolt	Phosphate	No	Galvanized.
Y.W.C.A.	1	1 yr	Mixed	Phosphate	No	Galvanized.

(continued)

TABLE E-1, Cont.

Name of Owner	Type of Problem	Reduction in Problems (Yes/No)	Performance Satisfaction (Yes/No)	Occupant Comment Favorable (Yes/No)
Clise Agency	Plugged & leaking pipes.	Yes	Yes	Yes
Harsh Investment Co.	Plugged pipes; colored water.	Yes	Yes	Yes
Westlake Developers	Plugged pipes.	Yes	Yes	-
Medical-Dental Bldg	Fixture staining; plugged pipes; colored water; leaks.	Yes	Yes	Yes
Vance Corp.	Colored water; leaks.	Yes	Yes	Yes
Rainier Bank	Plugged pipes; colored water; leaks; staining; rust.	Yes	Yes	Yes
C. K. Galland Home	Colored water; deteriorating pipes.	Yes	Yes	-
Magnolia Ct. Apts.	Colored water; plugged pipes.	Yes	Yes	Yes
Shannon Condo. Assoc.	Plugged pipes.	Yes	Yes	-
Leith Apts.	Colored water; plugged pipes; rusted pipes.	Yes	No	-
Sander Building Corp.	Colored water; leaks.	Yes	Yes	-
Melrose Co-Op	Rust.	Yes	Somewhat Yes to	-
America West Corp.	Fixture staining; colored water; plugged pipes.	Somewhat	Somewhat	-
Unico Properties	Colored water; high maintenance costs.	Yes	Yes	-
University Plaza	Plugged pipes.	Yes	Yes	-
Seattle Housing Auth.	Colored water; plugged pipes; leaks.	Yes	Yes	No
Laurelhurst Apts.	Rust.	Yes	Yes	Yes
Y.W.C.A.	Plugged pipes; colored water.	Yes	Yes	Yes

TABLE B-2. WATER QUALITY SURVEY SUMMARY

Parameter	Polyphosphate Systems	Silicate Systems	Average Cedar*	Average Tolt*
IRON				
Mean, mg/L	0.37	0.77	1.23	1.54
Range, mg/L	0.03-2.50	.075-2.60	0.09-6.38	0.06-4.32
% > 0.3 mg/L MCL	41	50	83	74
ZINC				
Mean, mg/L	1.24	0.34	0.61	0.87
Range, mg/L	0.015-8.95	.06-1.16	0.005-2.59	0.04-4.45
% > 5.0 mg/L MCL	7	0	0	0
LEAD				
Mean, µg/L	9.7	12.8	9.0	14.6
Range, µg/L	0.5-49	4-55	0.5-107	1.5-91
% > 50 µg/L MCL	0	10	5	9
% > 25 µg/L MCL	7	10	5	15
CADMIUM				
Mean, µg/L	0.21	1.12	1.15	1.0
Range, µg/L	<0.05-.65	<0.05-3.6	0.05-5.8	0.05-4.7
% > 10 µg/L MCL	0	0	0	0
COPPER				
Mean, mg/L	0.13	0.13	0.125	0.56
Range, mg/L	<0.01-0.71	.02-0.70	<0.01-1.02	0.02-2.53
% > 1.0 mg/L MCL	0	0	2.5	25.5
COLOR				
Mean	9	32	28	57
Range	6-17	7-115	12-70	13-160
% > 15 MCL	3	60	68	95

*Based on 1979-80 RWQM corrosion complaint samples.

Polyphosphate Systems --

Table E-2 demonstrates that the polyphosphate systems were effective in controlling corrosion-caused deterioration in standing water quality. For most of the parameters measured, only slight increases over the running cold water control samples occurred in the 24-hour standing water samples. Other investigations have also found that polyphosphates are effective in reducing corrosion.[3,4,5]

Table E-2 points out that iron and cadmium concentrations, and apparent color, were subsequently lower for the polyphosphate systems than for the average Cedar and Tolt conditions. The averages for the polyphosphate systems were 70% lower than the average Cedar condition for iron leaching and color concentration, demonstrating the effectiveness of polyphosphates in reducing iron corrosion.

Mean zinc concentrations for the polyphosphate systems, however, were approximately twice the average Cedar values and several values were greater than the MCL of 5.0 mg/L. This points out that polyphosphate systems may not be effective in reducing zinc, lead and copper corrosion.

Lead and copper concentrations also did not show any improvement over the average Cedar or Tolt values.

Silicate Systems --

The silicate feed systems did not show results as promising as the polyphosphate systems. Only iron and zinc concentrations were less than the average Cedar or Tolt condition. Lead, cadmium, copper and color were approximately equal to the Cedar averages.

It should be noted that only about 10 buildings in the Seattle area have silicate systems and that this does not provide a significant number of sample locations to draw statistically valid conclusions. Also, 4 of the 10 samples had very low silicate concentrations even though they were feeding silicate.

It should also be noted that further investigation is needed to determine corrosion rate reductions effected by point-of-use corrosion inhibitor systems for commonly used plumbing materials. The results presented in this report only represent observed corrosion reduction trends and not precise corrosion reduction values.

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2. Standard Methods for the Examination of Water and Wastewater, 14th edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation, Washington, D.C., 1976.

3. Sverepa, O., Anti-Corrosive Treatment of Hot Water with the Aid of Polyphosphates. Koroze Ochrana Mater (Czech.) Vol. 14, No. 4 (1970).

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